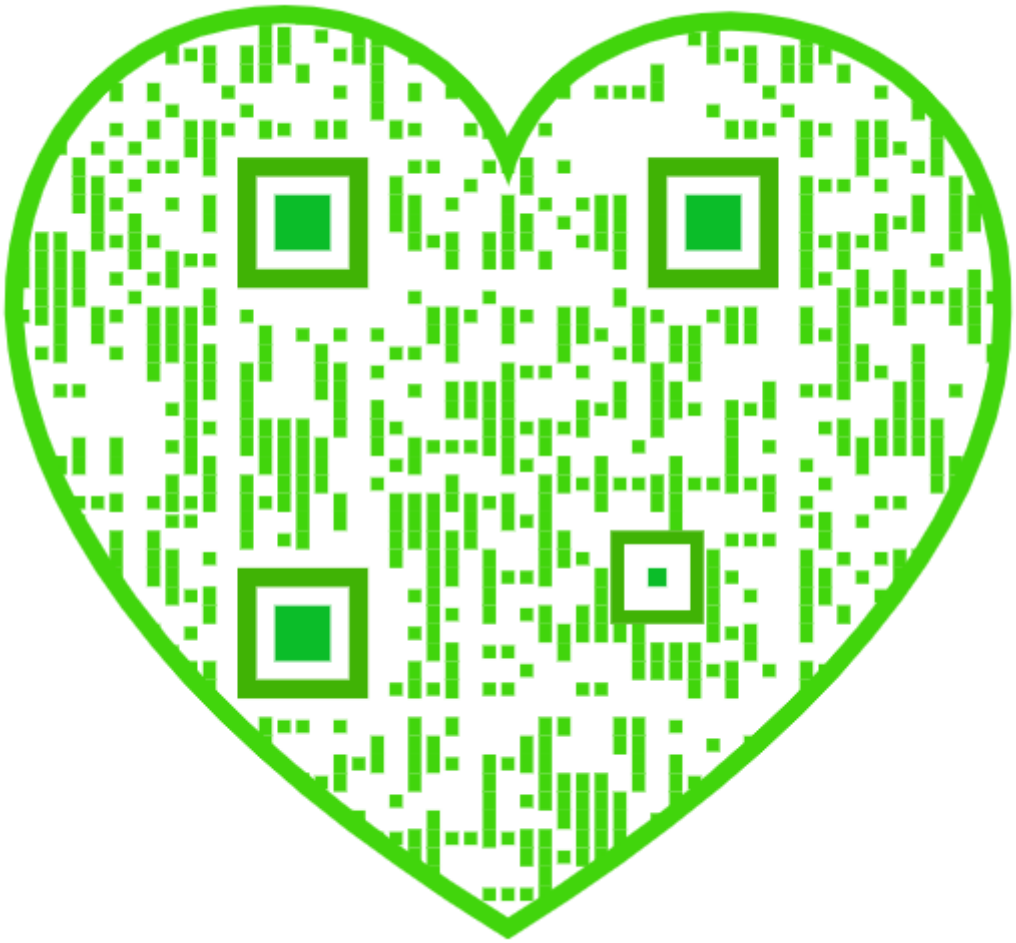


SEWAGE DISPOSAL

Published by the

McGraw-Hill Book Company

New York

Successors to the Book Departments of the

McGraw Publishing Company · Hill Publishing Company

Publishers of Books for

Electrical World
The Engineering and Mining Journal
Engineering Record
American Machinist
Electric Railway Journal
Coal Age
Metallurgical and Chemical Engineering
Power

SEWAGE DISPOSAL

BY

GEORGE W. FULLER

CONSULTING ENGINEER AND SANITARY EXPERT

Member of the American Society of Civil Engineers, the American Institute of Consulting Engineers, the American Society of Mechanical Engineers, the American Chemical Society, The Society of American Bacteriologists, The American Public Health Association, etc.

McGRAW-HILL BOOK COMPANY

239 WEST 39TH STREET, NEW YORK

6 BOUVERIE STREET, LONDON, E. C.

1912

COPYRIGHT, 1912
BY THE
MCGRAW-HILL BOOK COMPANY

PRINTED AND ELECTROTYPED
BY THE MAPLE PRESS
YORK, PA.

166501
SEP 10 1912
EXD
F75
6701378

PREFACE

The aim of this book has been to record the more important recent developments in the field of sewage disposal, and to give the present status of both the theory and practice. No attempt has been made to digest all of the literature of the subject. On the contrary, the book is rather the impress of twenty-five years' intimate association with this branch of sanitary work.

While the book deals essentially with American experience, European practice, which is richer and broader in many ways, has not been ignored entirely. There is no occasion for writing a book on European practice, which has been well set forth by several authors in fairly recent volumes.

The book is divided into four parts of approximately equal size. The first part is devoted to a somewhat lengthy description of the composition of sewage and the behavior of bacterial and biochemical processes in the decomposition of sewage. The importance of oxygen and deoxygenation, not only as a means of measuring the strength of sewage but in relation to proper conditions of the flow of sewage through collecting systems and various disposal devices, is discussed rather fully. The practical purpose of this is to show how to prevent or lessen "putrefaction" with its objectionable odors. The significance of sewage disposal problems from various angles is explained in detail. In particular the relation of sewage bacteria to shellfish pollution is discussed with thoroughness at a time when this problem is being actively considered by Federal and State authorities, who differ from the oyster growers in their views on several points.

The second part of the book is devoted to a recital of American experience in the disposal of sewage by dilution in inland streams, lakes, tidal estuaries and oceans. Although several early American reports upon this subject were prepared with much thoroughness, they have not received the attention in recent years that they are entitled to. The prevailing method in America of disposing of sewage by dilution has been applied in a faulty way in many instances, and corrective measures are needed. It is not necessary, however, in a majority of cases,

to abandon this method in favor of complete purification. The limiting factors and conditions in present practice are described at length, with suitable summaries.

The third part of this book deals with what have been generally called preparatory arrangements for the treatment of sewage. Screening, settling tanks, septic tanks, chemical precipitation tanks, electrolytic treatment and strainers are discussed in much detail, particularly septicization in two-story tanks. Résumés as to their present standing are given for each device.

The fourth part deals with filtration matters with a view to recording present practice. The closing pages of the book are devoted to aeration, sterilization and ozonization processes as they are now understood, with a few explanations as to institutional and residential plants, and a final comparative summary of general costs and efficiencies.

If any particular veiwpoint has prevailed in connection with the preparation of this book, it is that of the operator of disposal works. I desire to acknowledge my obligation, for data and aid, to Mr. C. B. Hoover, Mr. E. S. Chase and Mr. R. S. Lanphear, in charge of the operation of the disposal works at Columbus, Ohio; Reading, Pa.; and Plainfield, N. J., respectively.

At a time when medical authorities have a tendency to favor complete sewage purification regardless of the need or cost of such a project, it is hoped that the results of practical accomplishments as described in this book may be of aid. The same may be said as to the descriptions of the underlying chemical, biological and physical conditions which should receive attention from the engineer who has to design and build disposal works either for dispersion in large bodies of water or for clarification, filtration or sterilization.

Use has been made freely in this book of various professional papers prepared in recent years by me and also professional reports which I have made both individually and as a member of the former firm of Hering & Fuller. Lawrence data have also been used freely and suggestions have been received from Mr. H. W. Clark in regard to some of the reports of the Massachusetts State Board of Health since 1894, when there was published a summary of results, prepared by me, of the first seven years of operation of the Lawrence experiment station.

I desire to express my obligations to the large number of engineers and others for their courtesy in furnishing material

for this book. In the preparation of the manuscript I have been aided materially by my partner, Mr. James C. Harding, and by my secretary, Mr. George H. Scott. I am also indebted for helpful suggestions and criticisms in connection with the reading of the proofs to Messrs. E. G. Manahan, W. G. Taylor, and Langdon Pearse and to Dr. Arthur Lederer. The preparation of the index has been largely the work of my son, Mr. Myron E. Fuller.

NEW YORK, *April*, 1912.

G. W. F.

CONTENTS

CHAPTER I

PAGES

COMPOSITION OF SEWAGE 1–49

General characteristics. Early records of composition. Recent records of composition. Variations in quantity and quality. Trade wastes. Solid matters in sewage. Fats. Dissolved oxygen. Measures of organic matter. Stability of organic matter. Atmospheric oxygen consumed. Phelp's deoxygenation test. Bacteria. Résumé.

CHAPTER II

AEROBIC AND ANAEROBIC DECOMPOSITION OF SEWAGE 50–85

Classification of bacteria. Relation to oxygen. Relation to kind of food. Fermentation and putrefaction. Classification of decomposition processes. Enzymes. Conditions controlling bacterial growth. Behavior of organic matter in water. Prof. Nichol's views on decomposition. Prof. Drown's views on decomposition. Aerobic decomposition of sewage. Fresh, stale and septic sewage. Nitrification and denitrification. Reduction of mineral sulphates, desulphurization. Injuries to masonry. Relation of bacteria to different compounds of sulphur. Residual results of decomposition. Decomposition products. Characteristics of decomposition products. Sulphur, carbon and phosphorus compounds. Résumé.

CHAPTER III

SEWAGE BACTERIA AS RELATED TO OFFENSIVE ODORS 86–99

Relation of decomposition to nuisances. Oxidation and reduction of sewage. Minimizing of odors through aerobic decomposition. Proper methods for guarding against odors in systems of collecting sewers. Nature of objectionable sewage odors. Non-gaseous compounds. Gaseous products. Control of sulphureted hydrogen odors. Sanitary significance of offensive odors. Isolation. Résumé.

CHAPTER IV

SEWAGE BACTERIA AS RELATED TO PUBLIC WATER SUPPLIES . 100–24

Water transmission of cholera at Hamburg. Typhoid fever as related to polluted water supplies before and after filtration.

PAGES

Washington investigations. Water supply as related to typhoid and general death rates. The Hazen theorem. Sedgwick's and MacNutt's studies. Varying death rates in different cities with the same filtered water supply. Vital statistics of Cincinnati. Classification of causes of death. The Warren epidemic of gastro-enteritis. The Lowell and Lincoln epidemics of diarrhea. Longevity of typhoid bacilli in water. Résumé.

CHAPTER V

SEWAGE AS RELATED TO SHELLFISH 125–74

Shellfish products. Early instances of disease transmission through infected oysters. Recent outbreaks of typhoid fever due to infected shellfish. Relation of polluted shellfish to the general prevalence of typhoid fever. The life history of the oyster. The detection of typhoid fever germs in oysters and in water. Life of typhoid fever germs in sea water. Bacterial contents of unpolluted sea water. Bacterial contents of oysters and other shellfish taken from unpolluted waters. Life of typhoid fever germs in live and dead oysters. Resistance of typhoid germs to heat. Relative vitability of bacillus coli and bacillus typhosus in water. Pollution on the outside of oysters. Relaying of oysters. Sanitary conditions as shown by inspection of layings of oysters and other shellfish. Summary of evidence as to shellfish pollution. Shellfish hibernation. Position of State authorities on question of shellfish pollution. U. S. Board of Food and Drug Inspection. The oysterman's viewpoint. Action of State authorities. Report of Committe of American Public Health Association. Legal decisions regarding oyster pollution. Résumé.

CHAPTER VI

THE PROBLEM OF SEWAGE DISPOSAL 175–83

Definition of problem. Wide ranges in conditions met. Illustrations of varying types of problems. Economical aspects. Relation to public water supplies. Relation to shellfish. ' Pollution laws.

CHAPTER VII

EXPERIMENTAL METHODS AS APPLIED TO SEWAGE DISPOSAL PROBLEMS 184–200

Benefits of improved sanitary works. New conditions which have been encountered. Experimental methods in America. Object and advantages of experimental methods. Experimental methods in Europe. Résumé.

CHAPTER VIII

PAGES

DILUTION IN INLAND STREAMS 201–76

Required freedom from nuisance. Processes involved. Historical developments. Extent of use. Self-purification of streams. The question of policy as to bacterial removal. Corrective measures. Degree of dilution—the oxygen balance. Dispersion,—mixing. Residual oxygen. Atmospheric oxygen dissolved in water. Initial oxygen. Reaeration. Seasonal effects. Aquatic growths. Time factor. Caution necessary. Résumé of American investigations of the dilution method. Hering's review of evidence in 1887. Stearn's summary on the pollution of Massachusetts streams in 1890. Ohio investigations by Hazen in 1897–98. Massachusetts data of 1902. Chicago drainage canal litigation. Sanitary condition of Merrimac river in 1908. Wisner's report on the Chicago drainage canal in 1911. Significance of flora and fauna in natural waters. Résumé.

CHAPTER IX

DILUTION IN LARGE LAKES 277–317

Similarity to rivers. Dissimilarity to rivers. The physics, chemistry and biology of lakes. Birge and Juday's investigations of Wisconsin lakes. Practical accomplishments of lake cities. Sewage pollution of Lake Erie. Sewage disposal at Toronto, Cleveland, Rochester, Erie, Oswego, Milwaukee, Ithaca, and Madison, Wis.

CHAPTER X

DILUTION IN OCEANS AND TIDAL ESTUARIES 318–72

Statement of special factors involved. Disposal of sewage in Boston harbor. Providence harbor experiences. First sterilization plant at Red Bank, N. J. Baltimore disposal projects. Charles river basin. New York harbor and vicinity. The Passaic valley project. New York bay Pollution Commission. Metropolitan Sewage Commission. Report of Col. Black and Prof. Phelps. Standard of 70 per cent. oxygen. Reaeration. Streaming effect. General principles of diffusion. Gowanus canal flushing tunnel. New Bedford disposal project. Los Angeles project.

CHAPTER XI

SEWAGE TREATMENT WORKS 373–77

Objects sought. Outline of methods of treatment. Screens. Sedimentation. Chemical precipitation. Septicization. Strainers, roughing filters, slate beds, etc. Filtration. Sterilization. Combinations and modifications.

CHAPTER XII

PAGES

SCREENING 378–92

Utility. Kinds of screens. Efficiency of screening. Medium-sized screens. Plainfield screens. Mechanical appliances. The Reading rotary fine screen. Résumé.

CHAPTER XIII

PLAIN SEDIMENTATION 393–465

History and extent of use. Grit chambers. Sewage skimming tank. Grease removal. Theory of sedimentation. Velocity of settling particles. Removal of impurities. Influence of age and strength of sewage. Influence of temperature. Types of tanks and basins. Features of design. Vertical tanks. Details for sludge removal. Sludge removal devices. Quantity of sludge. Frequency of cleaning. Treatment and disposal of sludge. Sludge pressing. Sludge beds. Air drying of sludge. Dispersion in water. Lagooning. Filling or dumping. Digestion tanks. Trenching. Covered sludge trenches. Incineration. Destructive distillation. Mechanical drying. Sludge from final settling basins. Résumé.

CHAPTER XIV

SEPTICIZATION IN CONNECTION WITH SEDIMENTATION 466–534

Two phases of process. Effect upon organic matter. Relation to nitrification. Oversepticization. Sludge digestion. History and uses. Efficiency and utility. Types of tanks. Single-story septic tanks. Septic tanks as described at Baltimore. Gasification. Gasification of soluble matters. Action of enzymes. Kind of organic matter. Composition of gases. Hydrogen sulphide. Significance of gas formation. Scum formation. Digestion of solids. Quantity of sludge. Unloading of sludge. Size of tanks. Dissolved oxygen content. Cleaning operations. The odor question. Separate tanks. Two-story Hampton or Travis tanks. Two-story Emscher or Imhoff tanks. Extent of use. Construction features. Operating program. Results of operation. The odor question. Boston biolytic tank. Patent considerations. Résumé.

CHAPTER XV

CHEMICAL PRECIPITATION IN CONJUNCTION WITH SEDIMENTATION . 535–49

Providence project. Worcester project. Other projects. Principles of process. Efficiency and cost. Sludge disposal. Sludge pressing. Present status of chemical precipitation at Worcester and Providence. Résumé.

CHAPTER XVI

PAGES

ELECTROLYTIC TREATMENT 550–76

The Webster process. Santa Monica plant. Oklahoma City plant. Electrolytic tests at Louisville. Status of the electrolytic decomposition of metal plates. General description of electrolysis. Active electrodes. Cause of passivity—initial and acquired. Form in which iron leaves the plates. Influence on the process of oxygen. Influence on the process of hydrogen. Influence on the process of the solubility of the initial iron compounds. Influence of differences in potential. Influence on the formation of hydrate of current density. Influence on the formation of hydrate of reversing the direction of the electric current. Effect on the subsequent formation of hydrate of allowing electrodes to remain out of service. Percentage of metal wasted in this process. Resistance to the passage of electric current of films of iron oxide. Percentage of electric power wasted in this process. Conclusions as to iron electrodes. Conclusions at Louisville as to electrolytic formation of aluminum hydrate. Modifications in electrolytic apparatus. The chloride process of Mr. W. B. Bull. Electricity in direct oxidation processes. Résumé.

CHAPTER XVII

STRAINERS, SLATE BEDS AND COLLOIDORS 577–94

Historical development. Early Lawrence experience. Gardner experience. Aerated roughing filters. Columbus experience. Later Lawrence tests. Atlanta plants. Roughing filters at Atlanta. Slate beds. American experience. Hampton doctrine. Colloidors. Mechanical filtration. Résumé.

CHAPTER XVIII

BROAD IRRIGATION 595–614

Extent of use. Hygienic aspects. Quality of effluent. Bypassing. Raw vegetable question. Fly question. Financial aspects. Irrigating and manurial value. Capacity. European experiences. Paris sewage farms. Berlin sewage farms. Present status of broad irrigation. Résumé.

CHAPTER XIX

INTERMITTENT SAND FILTRATION 615–66

Nomenclature. Historical development. Extent of use. Efficiency. Capacity. Relation to preliminary treatment. Baltimore project. Clogging features. Intermittency and relation to oxygen. Character of filtering material. Mechanical analysis. Air and water capacities. Limitations in

PAGES

dosing. Kinds of material. Depth of filtering material. Underdrains. Stratification. Influence of temperature and composition of sewage upon nitrification. Biological construction. Surface clogging. Winter treatment. Trade wastes. Methods of distribution. Odors. Cost of construction and operation of intermittent sand filters. Sand filters for final treatment. Résumé.

CHAPTER XX

CONTACT FILTERS 667–89
Nomenclature. Historical development. Efficiency. Capacity. Relation to preliminary and final treatment. Principles of process. Character of filtering material. Mechanical analysis. Percentage of voids. Kind of materials. Size of material. Underdrainage. Depth of material. Features of construction. Filter walls and Floors. False bottoms. Features of operation. Rate of filling. Contact period. Rate of draining. Filling from below. Ripening. Permanency — clogging. Temperature conditions. Higher forms of life. Automatic dosing devices. Odors. Cost of construction and maintenance. Résumé.

CHAPTER XXI

SPRINKLING FILTERS 690–720
Nomenclature. Historical development. Practicability in winter. Extent of use. Efficiency. Capacity. Influence of strength of sewage. Relation to preliminary and final treatment. Characteristics of process. Time factor. Aeration. Absence of anaerobiosis. Intermittency. Ventilation. Surface clogging. Resting. Worms and flies. Character of filtering material. Size. Depth. Features of construction. Filter floor. Filter walls. False bottoms. Ventilators and cowls. Operating gallery. Head required. Distributing devices. Sprinkler nozzles. The odor question. Cost of construction and operation. Résumé.

CHAPTER XXII

AERATION 721–25
History of process. Increase in stability. Direct oxidation. Proposed aeration for New York city sewage.

CHAPTER XXIII

HYPOCHLORITE TREATMENT 726–31
Object. Historical development. Composition. Reaction. Required doses. Efficiency. Cost. Electrolytically prepared hypochlorites. Prospective use at sewage works.

CHAPTER XXIV

PAGES

OZONIZATION 732–34
Production of ozone. Relation to water purification. Relation to sewage purification. Recent progress in ozone production. Ozonization of sewage at Trenton, N. J. Efficiency and cost of ozone compared with hypochlorite treatment.

CHAPTER XXV

INSTITUTIONAL AND RESIDENTIAL PLANTS 735–38
Dissimilarity to municipal plants. Methods applicable. Montefiore Home, Bedford Hills, N. Y., disposal plant. Methods used at Kings Park, L. I., and Togus, Me. Subsurface irrigation. Prof. Marston's arrangement. Suggestions of Mr. Pratt.

CHAPTER XXVI

COMPARATIVE SUMMARY 739–44
General classification. Well-established methods. Recently developed methods. Methods of limited applicability. Waning methods. Unestablished methods. Comparative efficiency. Comparative cost. Needs for good management.

SEWAGE DISPOSAL

CHAPTER I

COMPOSITION OF SEWAGE

Sewage is the spent water supply of a community, together with those household wastes which are removed by water carriage in underground channels, supplemented in some instances by street washings and industrial wastes.

GENERAL CHARACTERISTICS

To most persons sewage conveys the idea of something that should be gotten out of sight and disposed of as quickly and as easily as possible. It is an unattractive waste product which forces itself to the attention of a community only on account of some special reason. If it produces foul odors, which come to the general attention of a community as a result of the sewage putrefying in conspicuous places, it receives discussion to the extent of criticism of those in charge of public works. Frequently the cost for improvements, however, is begrudgingly met only as a result of litigation.

The fact that sewage contains disease germs of the intestinal group, and in some instances infects the streams used by neighboring communities as a public water supply, engages the attention of some of the better-informed. The same is true in connection with oyster-pollution scares. Generally speaking, however, sewage and sewage disposal are subjects upon which comparatively little is known even as to general principles by the public at large. Consequently it is a subject upon which viewpoints vary immensely. Some people want exquisite perfection as to sewage disposal, while others object to anything that costs money for needed works.

To those responsible for sewage disposal projects there is need for careful study on account of the frequent changes which the

subject has undergone since the advent of the germ theory of disease, and particularly since the development of complicated biological processes, the full significance of which cannot be grasped at once. Different local conditions exert a profound influence upon the solution of various problems, and true progress can only be founded upon a sound appreciation of the significance of the contents of the underground channels called sewers, and of the principal physical, chemical and biological processes to which sewage may respond.

Sewage Disposal.—The art of sewage disposal deals with means at minimum cost for preventing nuisances. The latter may be due to malodorous products of decomposition, unsightly condition of bodies of water, or to the transmission of disease germs. In Chapter VI the scope of sewage problems is outlined at some little length. It is the intention to devote perhaps unusual space to emphasizing the foundation courses upon which is based the whole structure of sewage disposal as now understood. This means that decomposition products and methods by which they are brought about will be outlined. Citations will be given, exploiting with some thoroughness the relation between the objectionable bacteria in sewage and the contamination of water supplies and shellfish layings.

Importance of Bacteria.—Sewage contains millions and millions of bacteria. Most of them are not only harmless, but of genuine importance in the economy of nature through the scavenging work which they accomplish. Some of them, however, are dangerous on account of their causation of certain infectious diseases. Many of them may play an important rôle in the decomposition or bacteriolysis of sewage from which springs the malodorous gases and products associated with putrefactive nuisances.

No attempt here will be made to enter into methods of analyses in detail, such as are set forth in numerous books and reports upon the subject. It is important, however, at the outset to grasp, at least in general terms, the influence which the composition of sewage exerts upon putrefactive odors, the transmission of disease-producing germs, and the performances of certain devices or processes. No yardstick or means of measuring the composition of sewage along these lines is available to a wholly satisfactory degree. The remainder of this chapter is devoted to a recital of some of the evidence available on the

composition of sewage. It is set forth partly as an introduction to the succeeding preliminary chapters leading to a statement of the sewage problem. It is given partly for purposes of reference and to indicate the author's experience as to data and methods which are now most helpful, as well as lines along which improvements will be most sought in the future by those responsible for the construction and maintenance of sewage disposal works.

EARLY RECORDS OF COMPOSITION

The first records of which we have knowledge, showing the amount of the chief constituents of sewage, per capita per day, are found in the notes and lectures by the late Dr. Letheby. They are reprinted in a book (page 137) called "The Sewage Question," published in London in 1872 by Balliere, Tyndall and Cox. These results are averages obtained from a great number of analyses by Dr. Letheby of the sewage discharged at all hours and at all seasons from the outfalls of ten of the large London City sewers, whose ordinary daily rate of flow at mid day was about five million gallons. These results are in close accord with those obtained in 1857 by Dr. Hoffman and Mr. Witt in their inquiries into the average composition of London sewage, and whose samples were taken hourly during the full 24 hours from the Savoy street sewer, and mixed to produce fair average samples. Almost identical results were obtained by Prof. Way in analyses of the Rugby sewage as the result of ninety-three analyses made from 1861 to 1863. Dr. Voelcker's estimate to the average composition is a little lower in some respects than that given by Dr. Letheby.

One of the most interesting features of Table 1 is the estimate of the relative amounts of the several constituents coming from excreta and from other sources. It is to be noted that the organic matter is not recorded in the form of nitrogen as ammonia or of oxygen consumed, but that it is indicated only as a total quantity, doubtless obtained by the loss on ignition of the residue on evaporation, and probably including some volatile mineral matter. However, the total nitrogen is given, presumably obtained by a combustion process, and it indicates that about one-fifth of the organic matter represents nitrogen.

TABLE 1.—DR. LETHEBY'S ESTIMATE OF THE AVERAGE AMOUNT OF THE PRINCIPAL CONSTITUENTS OF CITY SEWAGE EXPRESSED IN GRAMS PER CAPITA DAILY

		Total	From excreta	From other refuse
Organic nitrogen	Total	15.1	10.1	5.0
	Dissolved	13.2	0.1	4.1
	Suspended	1.9	1.0	0.9
Dissolved matters	Total	136.0	43.0	93.0
	Mineral	98.5	10.0	88.5
	Organic and volatile	37.5	33.0	4.5
Suspended matters	Total	93.0	19.0	74.0
	Mineral	53.5	3.0	50.5
	Organic and volatile	39.5	16.0	23.5
Total solids	Total	229.0	62.0	167.0
	Mineral	152.0	13.0	129.0
	Organic and volatile	77.0	49.0	28.0
Phosphoric acid	Total	4.3	2.4	1.9
	Dissolved	2.1	1.4	0.7
	Suspended	2.2	1.0	1.2
Potash	Total	3.3	1.9	1.4
	Dissolved	2.9	1.5	1.4
	Suspended	0.4	0.4	.....

Massachusetts Data.—In the special report on the examination of water supplies by the Massachusetts State Board of Health, 1890, Part I, page 788, Mr. F. P. Stearns, then Chief Engineer of the Board, estimated the leading constituents of sewage per capita daily, based upon analyses of the London sewage during the years 1883 and 1884, the Lawrence analyses as then available and a few analyses from Worcester, Mass., with results equivalent to the following:

TABLE 2.—MR. STEARNS' ESTIMATE OF THE AVERAGE AMOUNT OF THE PRINCIPAL CONSTITUENTS OF SEWAGE EXPRESSED IN GRAMS PER CAPITA DAILY

Nitrogen ...	as free ammonia	5.6
	as albuminoid ammonia	1.1
	total[1]	8.9
Dissolved solids		99.0
Chlorine		19.0

[1] This is added by the author, and is taken as the sum of the nitrogen as free ammonia and three times the nitrogen as albuminoid ammonia.

English Data.—The next published record of which we have knowledge concerning the amount of constituents of sewage per capita is found in Mr. Goodell's translation of Prof. Baumeister's work on "The Cleaning and Sewerage of Cities," the German edition of which appeared in 1890 and the English edition in the spring of 1891. Prof. Baumeister apparently made very careful inquiries into the volume of water used by the sixteen English cities from which samples of sewage were analyzed by the Royal Commission on River Pollution during the early 70's. He paid especial attention to the question of whether the population connected with the sewers corresponded with the number of persons used in figuring the results per capita. His results are given in Table 3 for sixteen representative English cities and also for the city of London, although it is presumable that his data for London are less satisfactory in some respects than those recorded in Table 1.

TABLE 3.—PROF. BAUMEISTER'S ESTIMATE OF THE AVERAGE AMOUNTS OF THE PRINCIPAL CONSTITUENTS OF SEWAGE, EXPRESSED IN GRAMS PER CAPITA DAILY

		London	Average of sixteen English cities
Total nitrogen		16	15
Dissolved matter		129	127
Suspended matter	Total	112	79
	Mineral	71	43
	Organic and volatile	41	36
Total solids		251	206

Massachusetts Data.—Records of the constituents of sewage per capita daily are found in the report of the Massachusetts State Board of Health for 1894, page 474, where is given an estimate from analyses, made under the charge of the author, of the fresh sewage of Lawrence, the Worcester State Lunatic Hospital, Marlboro, Gardner and Framingham. The results are based on one set of analyses from each place, in which the sewage was collected hourly (with few exceptions) and gagings made of the sewage at the same interval, thus allowing a representative analysis of the entire day's flow to be computed. No determinations were made of the total solids or of the matters in suspension. There is considerable variation in the results obtained from the several places, due in part to difficulty in estimating the population upon the sewerage systems. Connections had only been partially made at several of these places, and this required an estimate of the equivalent for a period of 24 hours of a considerable portion of the contributing population which worked during the day in factories in the town and resided outside the district connected to the sewers. Another complication resulted from the relatively large volume of ground water which entered the sewers. The constituents of this ground water had perhaps some connection with the contributing population, but for the most part it was believed to be independent thereof. In the results of the amount of constituents per capita, the ground water was disregarded, thus giving results which for this reason are perhaps a little too low. The average results of the five places mentioned are given in Table 4:

TABLE 4.—ESTIMATE IN THE 1894 REPORT OF THE MASSACHUSETTS STATE BOARD OF HEALTH OF THE PRINCIPAL CONSTITUENTS OF SEWAGE, EXPRESSED IN GRAMS PER CAPITA DAILY

Oxygen consumed.	2 minutes' boiling	13.50
	5 minutes' boiling	19.80
Nitrogen as.....	Free ammonia	6.40
	Albuminoid ammonia	2.25
	Organic	7.20
	Total	13.60
Chlorine		16.00
Fats		18.50
Bacteria[1]		322.00

[1] Expressed as billions per capita daily.

Published records of the constituents of sewage per capita are given in the report (1903) of Mr. X. H. Goodnough, Chief Engineer of the Massachusetts State Board of Health, relative to the Charles river dam at Boston. It is based upon frequent analyses of sewage at Andover, Brockton, Marlboro and Spencer, Mass., and the quantity of nitrogen as albuminoid ammonia is estimated to be 1.02 grams per capita daily. The remaining constituents of sewage from these places are not given, as the albuminoid ammonia was used for a special purpose in connection with the permissible amount of pollution which streams may receive without offensive odor.

Summary.—Summarizing the results of published records of estimates of the chief constituents of sewage per capita daily, giving due weight to those data which are based upon the most numerous analyses, the following average was computed by the author in a paper presented to the Boston Society of Arts in 1903:

TABLE 5.—ESTIMATED APPROXIMATE AVERAGE AMOUNTS OF THE PRINCIPAL CONSTITUENTS OF SEWAGE, BASED ON FOREGOING DATA AND EXPRESSED IN GRAMS PER CAPITA DAILY

Oxygen consumed.	2 minutes' boiling	15.0
	5 minutes' boiling	22.0
Nitrogen as	Free ammonia	7.0
	Albuminoid ammonia	2.5
	Organic	8.0
	Total	15.0
Chlorine		19.0
Fats		19.0
Dissolved matters.	Total	136.0
	Mineral	99.0
	Organic and volatile	37.0
Suspended matters.	Total	93.0
	Mineral	53.0
	Organic and volatile	40.0
Total solids	Total	229.0
	Mineral	152.0
	Organic and volatile	77.0

This average is a composite result, and its several items do not specifically refer to the same sewage. The data of Table 5

represent in general the sewage from combined systems, due to the predominancy of English evidence, although the sewers in each of the Massachusetts cities studied in connection with Table 4 were designed, with the exception of those at Lawrence, on the separate system. The solids and suspended matters are based on London evidence, where there is a considerable quantity of street washings during storms. The amount of manufacturing refuse in the sewage represented by the above data is comparatively small. As to the different forms of nitrogen in the organic matter, the total amount found in London is subdivided as indicated by the Massachusetts data of 1894, which, as stated, represent fairly fresh sewage.

RECENT RECORDS OF COMPOSITION

Recently additional data have been obtained in this country, especially in connection with a number of sewage testing stations where conditions for sampling and analysis have been unusually complete. These refer particularly to the stations at Columbus, Ohio; the Institute of Technology, Boston, Mass.; Waterbury, Conn.; Gloversville, N. Y.; Philadelphia, Pa.; and Chicago, Ill. Valuable and well-known reports have been published in much detail upon the results obtained at these testing stations. The average results from these reports have been used in Table 6. Results at Waterbury, Conn., and Chicago, Ill., have not been published in full, but data from the former place are available in an article prepared by Mr. William Gavin Taylor on "Waterbury Sewage and its Septic Action," published in *Engineering News*, Vol. LXI, page 597. The Chicago data were obtained from a paper on "Sewage Disposal in the United States and Abroad," by Mr. Langdon Pearse, the engineer in charge, and reprinted from the *Journal of the Western Society of Engineers*, September, 1911. The Columbus report was prepared in 1905 by Mr. George A. Johnson. The Boston data, by Profs. Winslow and Phelps, appeared in the *Contributions of the Massachusetts Institute of Technology, Laboratory of Sanitary Research, Vol. IV.* The Gloversville data are in a report made in 1909 by Messrs. Harrison P. Eddy and Morrell Vrooman. The Philadelphia data come from a report of the Bureau of Surveys, Mr. George S. Webster, Chief Engineer, published in April, 1911. Still further data are to be found in the chapter on Sewage Composition in the

book on "Sewage Disposal," by Messrs. Kinnicutt, Winslow and Pratt, published in 1910. The data of that book are copied with respect to Lawrence and Worcester, Mass., Providence, R. I., Bradford and Sheffield, England. The Birmingham, England, data represent an average for the years 1901 to 1905 and are taken from a paper by Mr. John D. Watson, Chief Engineer of the Birmingham sewage disposal works, published in the *Proceedings of the Institution of Civil Engineers for* 1910, Vol. CLXXXI.

Table 6 shows average analyses of representative sewage as found in various American cities with combined sewers, according to the data available from the sources above stated. Table 7 contains data of Massachusetts cities having separate sewers, as given in the 1903 Report of the State Board of Health. Table 8 gives similar results for English cities, and is based largely on data presented to the Royal Commission except in the cases above mentioned. (See *Technology Quarterly*, Vol. XVI, page 151, for details recorded by the author in summarized form.) All results of analyses in Tables 6, 7 and 8 are expressed in parts per million. The average daily sewage flow per capita is given where available in United States gallons.

Per Capita Constituents.—Table 9 has been computed to show the estimated quantities of the principal constituents in grams per capita daily for the sewages of certain types of cities. In the first column are estimates for cities with separate sewers which receive but comparatively small or no discharges of trade wastes. They differ considerably from earlier estimates of the author. Further data from the Massachusetts and the Plainfield (N. J.) and Reading (Pa.) sewage disposal plants indicate an increase of about 25 per cent. in total suspended matter. The increase in organic matter is so confused with different methods of analyses that the data are not satisfactory. With changes in comparable data as to methods, there are well defined increases in strength over earlier estimates.

The London (England) data on the flow reaching the disposal works agree with the Columbus (Ohio) results obtained during dry weather. To some extent trade wastes are a factor with both of these combined systems. In the Columbus data as tabulated in Table 9 there is an allowance of 10 per cent. on account of the increase in impurities due to storm flows, as stated in Mr. George A. Johnson's report, page 34.

TABLE 6.—AVERAGE ANALYSES OF REPRESENTATIVE SEWAGE FROM COMBINED SEWERS OF AMERICAN CITIES, WITH ESTIMATED CORRESPONDING VOLUMES PER CAPITA DAILY

Place		Lawrence, Mass.	Boston, Mass.	Worcester, Mass.	Providence, R. I.	Waterbury, Conn.	Gloversville, N. Y.	Columbus, Ohio.	Philadelphia, Pa.[5]	Chicago, Ill.
Average daily flow		.....	245	118	99	.....	.....	121	.....	289
Oxygen consumed, 5 min., 212° F.		55.7[3]	56	120.7	93.6	46.0	95	56	76	38[4]
Nitrogen as	Free ammonia	41.7	13.9	17.13	18.4	7.8	12.0	11.5	4.0	8.8
	Alb. ammonia	6.6	.....	7.33	8.9	.....	.....	.....	.....	.....
	Organic	.....	9.1	.....	.....	14.8	23.0	9.7	6.3	7.6
Chlorine		143	.....	114	540[1]	48.0	158	67	39	40
Dissolved matters.	Total	568	.....	617.7	1318.0	.....	.....	811	.....	.....
	Mineral	394	.....	361.2	941	.....	.....	702	.....	.....
	Org. and vol.	174	.....	256.5	377	.....	.....	109	.....	.....
Suspended matters	Total	149	135	255.8	397	165	406	215	189	141
	Mineral	36	44	78	53.5	50	177	134	59	81
	Org. and vol.	113	91	177.8	343.5	115	229	81	130	60
Total solid matter.	Total	717	.....	873.5	1715.0	.....	.....	1026	.....	515[2]
	Mineral	430	.....	439.2	994.5	.....	.....	836	.....	.....
	Org. and vol.	287	.....	434.3	720.5	.....	.....	190	.....	.....
Fats		.....	.....	.....	.....	26	48	27	28	23

[1] Contains sea water. [2] Figure made up from determinations between October 5 and November 28, 1910. Average daily flow was 234 gallons per capita during that period. [3] Two minutes boiling. [4] Thirty minutes' boiling. [5] Separate sewers with trade wastes.

TABLE 7.—AVERAGE ANALYSES OF SEWAGE FROM SEPARATE SEWERS OF MASSACHUSETTS CITIES, WITH ESTIMATED CORRESPONDING VOLUMES PER CAPITA DAILY

Place		Brockton	Framingham	Gardner	Marlboro	Westboro
Oxygen consumed, 5 minutes 212° F.		162.7	47.3	49.2	44.4	35.5
Nitrogen as	Free ammonia	42.9	26.1	20.2	26.0	13.8
	Albuminoid ammonia	7.9	6.5	4.9	4.4	4.5
Chlorine		131.8	69.9	33.8	59.0	23.7
Dissolved matters	Total	624.2	375.3	229.7	310.7	186.8
	Mineral	251.8	136.6	98.9	103.2	76.1
	Organic and volatile	372.4	238.7	130.8	207.5	110.7
Suspended matters	Total	194.6	212.4	154.0	137.5	183.3
	Mineral	21.2	50.2	23.6	21.8	40.4
	Organic and volatile	173.4	162.2	130.4	115.7	136.9
Total solid matter	Total	818.8	587.7	383.7	448.2	370.1
	Mineral	393.6	288.9	154.4	229.3	157.1
	Organic and volatile	425.2	298.8	229.3	218.9	213.0

TABLE 8.—AVERAGE ANALYSES OF REPRESENTATIVE SEWAGE FROM ENGLISH CITIES, WITH ESTIMATED CORRESPONDING VOLUMES PER CAPITA DAILY

Place		Hudders-field	Leeds	Leicester	London, North	London, South	Manchester	Sheffield	Bradford	Birmingham
Average daily flow		108	60	60	48	60	72	48	65	36
Oxygen consumed (4 hrs., 80° F.)		99	126	107	80	67	118	79.6	202.3	259.2
Nitrogen as	Free ammonia	10.7	23.6	.....	39	34.5	24	32.18	47.8	41.6
	Alb. ammonia	6.05	11.3	14.2	4.3	4.3	6	9.02	32.8	16.2
	Organic									
	Total									
Chlorine		123	165	127.2	132	267	170	124.3	149	205
Dissolved matters	Total	715	1070	1045	870	1093	940	.....	1810	1229
	Mineral	597	.....	.....	565	755	470	.....	1510	.....
	Organic and volatile	118	.....	.....	305	338	470	.....	300	.....
Suspended matters	Total	346	610	635	483	408	370	417.5	840	718
	Mineral	164	240	.....	228	183	200	170.7	264	.....
	Organic and volatile	182	370	.....	225	225	170	246.8	576	.....
Total solid matters	Total	1061	1680	1680	1353	1501	1310	.....	2650	1947
	Mineral	761	.....	.....	793	938	670	.....	1774	.....
	Organic and volatile	300	.....	.....	560	563	640	.....	876	.....

The streets in Columbus tributary to the interceptor at the testing station were more extensively paved than is the case with many American cities. But there was and now is more sewage reaching the river through storm overflows than is the case at many other places with combined sewers.

The Chicago data in Table 9 are from the records of Mr. Langdon Pearse at the 39th Street pumping station. This is at the foot of the 16-foot interceptor along the lake front in the southern part of the city. It is understood that no overflows reach the lake. The population tributary to the station is estimated at 285,900, equal to about 20 per acre. The sewage is comparatively free of trade wastes, but surprisingly strong, especially in suspended matter. Probably this is explained largely by the condition of the soil and street surfacing, together with the fact that storm flows are taken fully into account.

Providence, R. I., is probably better paved than the southern part of Chicago, but the sewers receive considerable quantities of wastes from industrial establishments. The data as given in Table 9 are not unlike those from Chicago, although the source of the impurities, especially the suspended matters, is quite different. Storm overflows are something of a factor at Providence, but not to the extent that prevails at Columbus.

TABLE 9.—ESTIMATED AVERAGE QUANTITIES OF PRINCIPAL CONSTITUENTS IN GRAMS PER CAPITA DAILY OF SEWAGES OF VARIOUS TYPES

	Separate sewers	Combined sewers			
		London	Columbus	Chicago	Providence
Oxygen consumed, boiled 5 minutes	20	25	30	42 [1]	35
Total nitrogen	16	13	14.4	18.5	17
Chlorine	18	24	32	44	... [2]
Suspended matters, Total	60	87	98	155	150
Suspended matters, Mineral	10	41	51	89	20 [2]
Suspended matters, Organic and volatile	50	46	47	66	130 [2]
Free carbonic acid	.....	.....	13.6	.....	.....
Fats	.....	.....	19.1	26	.....

[1] 30 minutes boiling.

[2] Results distorted by the presence of sea water.

The Metropolitan Sewerage Commission of New York City estimates in its 1910 report that street wastes add about 22 per cent. to the dry suspended solids in the city sewage.

Mr. G. M. Wisner's 1911 Report on Sewage Disposal at Chicago, page 19, gives an estimate of dry suspended solids, exclusive of the principal industrial wastes, of 137,000 tons annually, equal to about 155 grams per capita daily. This does not include the street washings that are flushed in by the street cleaners, nor the matters from the stock-yards or packing houses. From the two latter sources it is stated, page 58, that as much as one-fifth of the entire settling suspended matter is obtained.

Enough has been said to indicate that as to industrial wastes each problem should be studied on its own merits.

Dissolved mineral matters are of but little significance as a rule, although they may be factors of importance due to the mineralized character of the seepage if related to sea water or very hard water.

Influence of Local Conditions.—Sewage varies so tremendously in its composition at different hours of the day in the same sewer, and it is influenced so much by the methods both of sampling and analysis, that the foregoing data are considered to be fair guides if carefully used. It is true that the average data for the several classes of sewage as here presented are not based on as comprehensive knowledge of exact local conditions as is desirable. To persons of a precise turn of mind it is not difficult to point out inconsistencies and the lack of important features needed in the study of the sludge question. The final answer is not at hand as to what specific influence is produced by different modes of living of the population considered; by different proportions of paved streets, by paving of different kinds and by the cleanliness with which the streets are kept; by the frequency and intensity of rainfall with special reference to storm overflows in trunk sewers; and by differences in the amount and character of waste products of various industries.

On the other hand, it is not to be forgotten that these estimated averages are ordinarily far safer guides than are the results of many scattering analyses. This will be appreciated by comparing the range in rates of flow and the several constituents of sewage as shown in Table 10. Again, in considering sewage disposal problems it is the duty of the engineer and sanitarian to give due regard to the future, for which no specific individual or

local data are available. Judgment should be based, therefore, on well-digested generalizations from past experiences which are well understood.

Computed Analyses.—Knowing approximately the number of persons connected with a sewerage system and the average sewage flow, information which within certain limits is essential for the proper design of the collecting sewers, it is feasible to estimate the average composition of the sewage from such data as given in Table 9. For purposes of ready comparison it is convenient to prepare tables or diagrams showing the composition of the sewage, based on such averages and corresponding to different degrees of dilution. "Grams per Capita Daily" give the same figures for the several constituents, corresponding to the different forms of expressing the analyses, when the volume of sewage in United States gallons per capita daily is as follows:

Parts per million.....264.0 gallons
Parts per hundred thousand.....26.4 gallons
Grains per U. S. gallon.....15.4 gallons
Grains per Imperial gallon.....18.5 gallons

If it is desired to estimate the composition of sewage corresponding to a strength of 100 gallons per capita daily, then the results in grams per capita daily should be multiplied by the fraction 264/100 to obtain figures in parts per million. By multiplying the latter by 8.34 the results are converted into pounds per million United States gallons.

It is stated by some that computed data as to the composition of sewage are not very satisfactory. The engineer, however, is forced to deal with estimates of future conditions when certain populations will have become connected with sewerage systems. Accordingly, he cannot be guided reliably by the analyses at present as to the sewage to be found later in a growing community. With a greater density of population and added connections to existing sewers, it is necessary for sewage disposal works to provide for future growth, and to deal with amounts of suspended matter, organic matter, etc., which correspond with future and not present conditions. Hence the importance of securing and wisely utilizing such sewage data as the foregoing. It is unfortunate that so many analytical data are lacking in records of the condition of sampling, sewage flow and population connected with the sewers.

VARIATIONS IN QUANTITY AND QUALITY

It is well known that sewage varies widely both in quality and quantity at different hours of the day and night. It is important to note the significance of this with regard to the capacity of works for the disposal of sewage and to keep it clearly in mind in collecting samples and noting the results of analyses. By comparing samples of weak sewage obtained during the late hours of the night with samples of strong sewage collected a few hours later, it is not difficult to obtain such a wide range in figures that the night sample might correspond to those from a day sample after undergoing a large degree of purification. In fact, there is reason to believe that procedures of this sort have been resorted to in some instances where proprietary devices have been under consideration. In order to illustrate the significance of variations and to emphasize the danger in dealing with results of analyses of a few scattering samples, Table 10 is given. It shows the percentages which the rates of flow and the amounts of the principal constituents of sewage at different hours of the day are of the average quantities. This table is computed from data given for the sewage purification works at Gardner, Mass., in the Massachusetts State Board of Health Report for 1898, page 624.

TABLE 10.—COMPARISON OF THE PERCENTAGES WHICH THE FLOW OF SEWAGE AND THE AMOUNT OF ITS DIFFERENT CONSTITUENTS AT DIFFERENT HOURS ARE OF THE AVERAGES FOR THE DAY

Hour	Rate of Flow	Residue on Evaporation			Nitrogen as		Oxygen Consumed	Chlorine
		Total	Dissolved	Suspended	Free Ammonia	Alb. Ammonia		
9–10 a. m....	124	143	126	180	150	180	158	99
11–12 a. m....	116	160	159	162	157	155	167	114
1–2 p. m....	123	129	131	125	107	107	110	127
3–4 p. m....	116	142	114	204	113	141	141	120
5–6 p. m....	107	123	137	93	116	99	92	217
7–8 p. m....	103	97	105	79	141	117	110	116
9–10 p. m....	92	67	76	49	84	66	85	75
11–12 p. m....	85	84	76	101	98	87	99	77
1–2 a. m....	74	35	43	16	35	31	22	53
3–4 a. m....	70	28	39	6	8	15	16	38
5–6 a. m....	77	32	44	8	16	14	19	38
7–8 a. m....	69	74	59	59	101	87	82	61

Dangers of Limited Data.—The dangers of attaching too much significance to the results of limited data as to volume and strength of sewage have long been appreciated by some. Years ago it resulted in the custom of rating the capacity of irrigation farms and intermittent sand filters according to the population connected with the sewers per unit area of filtering surface. This was no doubt a wise custom, and it has served a useful purpose. But it has its limitations, owing to the fact that the amounts of some of the constituents of sewage are quite independent of the numbers of the contributing population. This is due especially to variations in quantity and quality of manufacturing wastes and also to street washings which may be discharged into the sewers. Such limitations, of course, do not apply directly to residential and commercial communities which have separate sewers for the removal of storm water and of domestic wastes.

Variations at Columbus.—At Columbus this matter was studied with results which are shown during dry-weather conditions by Table 11, which is taken from page 33 of Mr. Johnson's Report on Sewage Purification, 1905.

A number of other data obtained from the Columbus sewage testing station as described by Mr. Johnson are of interest, due to the care with which the observations were made. Table 12 shows the differences in the amount of sewage flow in the main outfall sewer (or interceptor) during each day of the week, during the latter portion of a period of extremely dry weather:

Table 13 shows the variations, at different hours of the day and night on a Sunday during a period of dry weather, in the sewage flow at Columbus, as noted at the testing station, in comparision with week-day flows.

TABLE 11.—COMPARISON OF THE PERCENTAGES WHICH THE FLOW OF SEWAGE AT THE COLUMBUS OUTFALL AND THE AMOUNT OF ITS DIFFERENT CONSTITUENTS AT DIFFERENT HOURS ARE OF THE AVERAGES FOR THE DAY

Hour		12 a. m. to 2 a. m.	2 a. m. to 4 a. m.	4 a. m. to 6 a. m.	6 a. m. to 8 a. m.	8 a. m. to 10 a. m.	10 a. m. to 12 m.	12 m. to 2 p. m.	2 p. m. to 4 p. m.	4 p. m. to 6 p. m.	6 p. m. to 8 p. m.	8 p. m. to 10 p. m.	10 p. m. to 12 p. m.
Rate of Flow		88	83	80	89	113	117	115	117	115	103	92	89
Oxygen Consumed	Total	35	69	28	28	176	116	123	117	197	88	90	58
	Dissolved	42	23	29	29	181	136	49	149	149	81	87	68
	Suspended	27	123	27	27	169	92	92	81	254	96	92	46
Nitrogen as	Ammonia	73	56	42	49	108	109	110	167	147	99	99	84
	Organic	47	31	23	28	167	117	115	126	225	84	80	63
Chlorine		72	74	73	69	94	143	123	111	111	101	114	80
Suspended Matter	Total	59	43	37	37	213	145	110	110	165	94	54	52
	Volatile	29	28	18	29	156	160	129	109	229	109	64	50
	Fixed	81	53	52	43	257	134	96	112	116	83	46	54
Fats		33	26	30	22	81	111	111	81	307	163	81	74
Bacteria per cubic centimeter		75	47	36	56	92	167	139	167	103	125	106	81

TABLE 12.—SHOWING THE DAILY VOLUME OF EXTREME DRY-WEATHER SEWAGE FLOW AT COLUMBUS, OHIO
(Million Gallons)

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
7.3	9.1	8.5	8.5	8.4	8.6	8.6

TABLE 13.—HOURLY RELATION OF SUNDAY TO WEEK-DAY FLOWS AT COLUMBUS, OHIO

Hour ending	Per cent. which hourly rate of discharge is of the average		
	Sunday	Week day	Average
1 a. m.	105	83	86
2 a. m.	103	80	82
3 a. m.	97	77	79
4 a. m.	95	75	78
5 a. m.	91	74	76
6 a. m.	90	73	75
7 a. m.	90	73	75
8 a. m.	90	78	79
9 a. m.	96	97	96
10 a. m.	101	111	110
11 a. m.	105	118	117
12 m.	108	123	121
1 p. m.	108	124	122
2 p. m.	108	125	122
3 p. m.	108	125	122
4 p. m.	108	125	122
5 p. m.	107	125	122
6 p. m.	105	124	121
7 p. m.	103	117	114
8 p. m.	101	115	104
9 p. m.	100	97	98
10 p. m.	100	94	94
11 p. m.	99	90	91
12 m.	96	88	89

The Columbus sewers are built on the combined plan, and there has been more or less difficulty in the operation of the devices through which the sewage flows from the original sewers, leading to the river, into the interceptor. The latter parallels the river for the most part and is beneath the original sewers. The capacity of the main interceptor at Columbus is about 40 million gallons daily. Table 14, taken from page 20 of Mr. Johnson's report, shows rates of storm flow in the interceptor following a rain of 0.59 inch which fell within a few hours on April 20, 1905.

TABLE 14.—RELATION OF STORM TO DRY-WEATHER WEEK-DAY FLOWS

Hour of the day	Rate of discharge in million gallons per day of the intercepting sewer		Rainfall in inches, April 20, 1905	Per cent. which the storm flow was of the dry-weather week-day flow
	Average normal dry-weather flow	Storm flow, April 20, 1905		
6 a. m....	6.8	6.8	0	100
7 a. m....	6.8	6.8	.17	100
8 a. m....	7.3	16.1	.15	220
9 a. m....	9.0	27.3	.06	304
10 a. m....	10.3	30.5	.03	296
11 a. m....	11.0	30.5	.12	227
12 m.....	11.4	27.5	0	241
1 p. m...	11.5	22.0	0	191
2 p. m...	11.6	17.9	0	154
3 p. m...	11.6	16.1	0	139
4 p. m...	11.6	15.4	0	133
5 p. m...	11.6	14.7	0	127
6 p. m...	11.5	14.0	.02	122
7 p. m...	10.9	13.3	.01	122
8 p. m...	9.8	12.3	0	125
9 p. m...	9.1	11.3	0	124
10 p. m...	8.7	10.6	0	122
11 p. m...	8.4	10.4	0	124
12 p. m....	8.2	9.7	0	118

Following heavy rains there is much material which enters the sewers from the washing of the streets. There is also more or less of an accumulation of matters detached from the walls of the sewers. In particular are the first washings foul as regards organic matter.

Data on this feature of variation are available from quite a number of sources. With combined sewers it is a much more important item than with separate sewers. Where trade wastes become a factor it rises to still greater significance, as will be noted by studying the valuable report of Messrs. Eddy and Vrooman on the Gloversville, N. Y., sewage, which is quite highly impregnated with trade wastes from tanneries.

TRADE WASTES

The data of Tables 6 to 9, inclusive, indicate that marked deviations from the normal composition of sewage may be expected in manufacturing cities where the sewers receive substantial quantities of trade wastes. These data suffice to accentuate this general feature which for each particular style of trade waste should be investigated for each individual problem. Further data may be noted by consulting various city documents, of which note may be made of the following:

Gloversville, N. Y.—The effect of tannery wastes was well studied and recorded by Messrs. Eddy and Vrooman in a special report dated Aug. 7, 1909.

Hudson, Mass.—Wool wastes seriously interfered with the sewage purification works, as described by Mr. Frank A. Barbour in the *Journal of the Association of Engineering Societies*, September, 1911.

Paterson, N. J.—The trade wastes were carefully investigated and reported by Messrs. Hazen & Whipple in a special report dated June, 1906.

Worcester, Mass.—Pickling liquors from steel works make serious complications, as described by the Superintendent of Sewers in various annual reports.

An excellent clue to trade wastes in general as distinguished from sewage may be obtained from a report by Mr. H. W. Clark in the Massachusetts State Board of Health Report for the year 1909.

SOLID MATTERS IN SEWAGE

Much importance attaches to the amount of suspended matters in sewage. This is the portion, of course, which forms sewage sludge and appears in slips, small streams and especially mill ponds. Sewage sludge, which is the burdensome product to be dealt with in connection with sedimentation processes, is also a factor for consideration in connection with filtration. It is related quite closely to the capacity of plants, size of filtering material and cost of maintenance.

Table 15 shows the estimated total dry sludge or suspended matter in various sewages, as computed from the data in Tables 6 to 9 for American and English cities, with results expressed in different forms. Data for strong German sewages are given on

page 15 of Mr. A. Elliott Kimberly's translation of Dr. Schmeitzner's book on "Clarification of Sewage." Information is generally lacking as to the strength of the sewages corresponding with the results of the German analyses. The same is true of data from Lawrence, Mass., Waterbury, Conn., Gloversville, N. Y., and Philadelphia, Pa.

TABLE 15.—ESTIMATED TOTAL DRY SLUDGE OR SUSPENDED MATTER IN VARIOUS MUNICIPAL SEWAGES

Place	Parts per million	Grams per capita daily	Tons per million gallons, U. S.	Tons per 1000 population per annum
Plainfield, N. J.	173	60	0.72	24
Framingham, Mass	212	70	0.88	28
Boston, Mass	135	168	0.56	67
Gardner, Mass	154	50	0.64	20
Marlboro, Mass	137	57	0.57	23
Brockton, Mass	195	55	0.81	22
Worcester, Mass	256	175	1.06	70
Providence, R. I	397	149	1.65	60
Columbus, Ohio	215	98	0.90	39
Chicago, Ill	141	155	0.59	62
London (North), England	483	87	2.00	35
London (South), England	408	92	1.70	37
Huddersfield, England	346	142	1.44	57
Leeds, England	610	137	2.54	55
Leicester, England	635	143	2.64	57
Manchester, England	370	102	1.54	41
Birmingham, England	718	98	2.98	39
Bradford, England	840	207	3.50	83
Sheffield, England	417	76	1.73	31
Waterbury, Conn	165	.....	0.69	.....
Gloversville, N. Y	406	.....	1.70	.....
Philadelphia, Pa	189	.....	0.79	.....
Lawrence, Mass	149	.....	0.62	.....

The Metropolitan Sewerage Commission of New York City in its report of April 30, 1910, page 431, gives an estimate of the amount of dry suspended solids in the New York City sewage, as follows:

TABLE 16.—DRY SUSPENDED SOLIDS IN NEW YORK CITY SEWAGE

Material	Tons per 1000 inhabitants annually	Tons entering New York harbor annually
Feces	14	77,600
Toilet paper and newspaper	8	44,300
Soap and washings	11	60,900
Street wastes	8	44,300
Miscellaneous	4	22,200
Total	45	249,300

Weight of Sludge.—Wet sludge is from about two to fifty times as heavy and as bulky, roughly speaking, as dry sludge, depending upon the amount of water in the sludge. As found in ordinary settling tanks, the sludge contains about 90 per cent. of water. The specific gravity varies from about 1.02 to 1.06, making a cubic yard weigh from about 1720 to 1790 pounds. It depends upon the mineral matter, fats, entrained gases, porosity, septicization and other factors of the sludge in question.

Differences in weight of sludge due to differences in water content may be computed accurately from the following formula:

$$W' = W\frac{(100-E)}{(100-M)}$$

Where W is the weight of the existing unmodified sludge.
W' is the weight of the changed or modified sludge.
E is the per cent. of water in the existing sludge.
M is the per cent. of water in the modified sludge.

Example.—If a mass of sludge weighs 100 tons and contains 90 per cent. of water, what will be its weight if the water content is changed to 80 per cent.?

$$W' = 100\frac{(100-90)}{(100-80)} = 100\frac{(10)}{(20)} = 50 \text{ tons.}$$

Volume of Sludge.—The volume of sludge is in some ways a more convenient form of expression for the engineer than is the weight. The specific gravity as well as the per cent. of water should be determined. Changes in volume incident to changes

in water content may be approximated within certain limits by the formula above given. Limitations in accuracy come through the varying specific gravity. Diagrams on this point are shown opposite pages 161–62 of the 1911 Philadelphia report. To what extent they are representative of other sludges is not known.

Classes of Suspended Matter.—Part of the suspended solid matters will float, part will subside, and part is so finely divided that it will not respond to the laws of subsidence or flotation. Other solid matters will dissolve in sewage and form what is spoken of as a "true solution" as distinguished from "colloidal matters." In sewage work the expression "colloidal matters" is used rather loosely to mean those suspended matters in a state of very fine division which cannot be removed by sedimentation in practice. They exist apparently in a state of pseudo-solution or micro-suspension, as explained in the 1905 Columbus report, page 40. With the sewage there tested, about 60 out of 210 parts of total suspended matter could not be practically removed except by filtration or with the aid of coagulation. In summary, therefore, suspended matters in sewage may be divided into floating materials which form scum, into subsidable matters which form sludge, and into the finely divided particles which pass through all screens and sedimentation basins and which are spoken of as "non-settling" solids, as "non-subsidable" solids, as "colloidal" solids, or as solids "unresponsive to subsidence."

Records by Weight.—In America practically all records up to within a very short time at least have been obtained as the weight of the total suspended matter. These results were obtained in earlier years by noting the difference between the residue upon evaporation of a known volume of untreated sewage and of sewage which had been freed of suspended matter by passing through a number of thicknesses of filter-paper. During the past few years the results have been obtained for the most part with the aid of the Gooch crucible in which is a film of asbestos felt and with a record of the weight of the dry crucible and felt. Then a known volume of sewage is filtered through the felt and the increased weight due to the dry solid matters so removed from the sewage is determined.

Turbidity.—In a few instances the amount of the suspended matter has been noted by operators of disposal works with the aid of turbidity standards containing in various bottles

different known weights of diatomaceous earth corresponding to different numbers of parts per million of suspended matter. This procedure, so helpful in the operation of water purification plants dealing with muddy rivers, has only a limited application in connection with sewage works. The reason of this is that many sewages are dark-colored on account of their age and the formation of sulphide of iron; and, moreover, the suspended matter is apt to be so coarse that the results are not satisfactory. For fresh sewages after sedimentation or filtration the data are of aid. Mr. H. W. Clark, in the 1904 Report of the Massachusetts State Board of Health, page 246, describes some special standards made of the suspended matters of the effluents of coarse-grain filters.

Records by Volume.—In Germany advantage is taken of quick methods of noting the approximate volume of suspended matter that settles in conical-shaped glasses in a period of two hours. The amount of suspended matter capable of removal in settling tanks is taken as the number of cubic centimeters of deposit found in the conical bottom at the end of two hours. This is particularly the practice in the Emscher district of Germany, as will be noted from communications emanating from Dr. Karl Imhoff, Engineer of the Emscher Sewerage District, Germany, and contained in the *Engineering Record* of Sept. 3, 1910 and Aug. 31, 1911. It is not serviceable for weak American sewages.

FATS

Coagulated soap and grease from the kitchens form quite a portion of the suspended matters in sewage, particularly where the water is hard. Fats are determined by ether extraction and results of analyses have been recorded in tables 6 to 9, inclusive, in the instance of quite a number of representative sewages.

In places like Bradford, England and Hudson, Mass., the industrial wastes have contained so much fatty matter as to put out of commission the ordinary sewage disposal plant. At Bradford, England, these wastes continue to enter the sewers and the disposal works are modified to facilitate the extraction of grease on a commercial basis. At Hudson, Mass., however, it was found necessary to remove the fatty matters from the sewers owing to severe clogging of the intermittent sand filters which resulted from wool washings.

Fatty matters do not seem to be as serious a burden for coarse-grained filters as in the case where filtration processes with fine material are used. However, it is believed by some that increasing care should be taken to prevent the entrance of grease into sewers. With suitable grease traps this is not a particularly difficult or expensive undertaking, as a rule.

DISSOLVED OXYGEN

At its point of origin in the various households and industrial establishments of a community, sewage is naturally well supplied with oxygen as it is made up largely of the public water supply. Bacterial activities proceed to utilize the oxygen, so that in the outfall sewers of practically all large cities there is little or no oxygen present in the sewage. This question was taken up by the author in considerable detail at the Lawrence Experiment Station in 1894, as described in the Annual Report of the Massachusetts State Board of Health for that year. Briefly it may be said that in the Lawrence street sewer the sewage is ordinarily fresh and contains a substantial proportion of dissolved oxygen, as noted on page 459 of that report. As the sewage passes through a small pipe some 4000 feet long on its way to the experiment station, bacterial activities consume the oxygen and practically without exception it has been absent when the sewage is applied to the experimental filters.

At Columbus, Ohio, as stated in Mr. Johnson's report of 1905, page 36, dissolved oxygen was ordinarily lacking in the outfall sewer at the testing station from about 10 a.m to about 4 p.m. During the remainder of the day dissolved oxygen was present in varying amounts up to a maximum of about 3 parts per million from about 2 a.m. to 7 a.m. For the full 24-hour period the average amount of dissolved oxygen was about 0.5 part per million. As delivered through the force main to the sewage purification works of Columbus, the sewage is understood to be uniformly lacking in dissolved oxygen, as noted from the operation of the main works.

At Reading, Pa., dissolved oxygen is stated by Mr. E. S. Chase to be practically never lacking in the sewage as it enters the main settling tank nor indeed at any step in the purification process.

At Plainfield, N. J., Mr. R. S. Lanphear states in an article in the *Engineering Record* of July 1, 1911, that hourly determina-

tions of the quantity of oxygen in the sewage show a range from less than 1 part per million during the afternoon hours to from 6 to 7 parts in the early morning hours.

Sufficient has been said to indicate the striking difference as to the oxygen content of different sewages. Initially the amount of oxygen in the water supply of a community is of importance. Much significance is to be attached to the condition of the sewers as to smooth interior surfaces and ample velocity at all times to prevent the stranding of solids which promote putrefaction. Finally, time is of the essence of the findings as to oxygen content. Usually oxygen is found in appreciable quantities at all times in the outlet sewers of small communities, but it is almost always lacking in the outfall sewers of large cities.

ORGANIC MATTER

One of the unfortunate features regarding data on the composition of sewage has been the inadequateness with which conventional analytical methods measure the capacity of the organic matter for consuming oxygen in connection with both filtration and dilution processes. Neither do they give a satisfactory clue as to the nature, comminution or origin of the organic matter, whether of animal or vegetable source.

Loss on Ignition.—The old method of regarding the loss on ignition as organic matter is crude, as the results also include quite a portion of volatile mineral matters, and, further, give no clue to the character of the organic material with reference either to its power for consuming oxygen or to its origin.

Nitrogenous Matter.—The amount of nitrogen in the form of the ammonias is more helpful. The crude organic matter is supposed to be measured by the albuminoid ammonia, obtained by distillation after addition of alkaline permanganate. It is of assistance in allowing comparisons to be made of purified sewage and of natural waters in which the organic matter is in a fairly stable condition. In raw sewage, however, the percentage of nitrogenous organic matter which appears in the form of the ammonias is quite variable, and depends upon a number of factors. Especially is this true of the nitrogen in the form of albuminoid ammonia as compared with the total organic nitrogen in raw sewage. This has led during recent years to direct determinations of the nitrogen in the organic matter by means of the Kjeldahl process.

Table 17 shows some comparisons by percentages of the several amounts of the different forms of nitrogen as found at various intervals in an experiment described on page 461 of the 1894 Report of the Massachusetts State Board of Health, wherein a sample of fresh sewage was allowed to decompose by standing in the laboratory. The nitrogen cycle is described in Chapter II.

TABLE 17.—COMPARISON OF THE RELATIVE AMOUNTS OF NITROGEN IN DIFFERENT FORMS

Day	Hour	Percentage of total nitrogen found as				
		Organic nitrogen (Kjeldahl)	Albuminoid ammonia	Free ammonia	Nitrites and nitrates	Percentage which nitrogen as albuminoid ammonia is of organic nitrogen (Kjeldahl)
March 11.	10.30 a. m.	64	13	30	6.0	20
March 11.	12.30 p. m.	63	13	32	5.0	20
March 11.	3.00 p. m.	62	13	33	5.0	21
March 11.	6.00 p. m.	59	13	37	4.0	22
March 12.	8.00 a. m.	37	14	62	0.4	37
March 12.	12.00 m....	32	15	67	0.3	47
March 12.	5.00 p. m.	35	13	66	0.0	39
March 12.	10.30 a. m.	32	13	68	0.0	41
March 14.	10.30 a. m.	30	14	74	0.0	44
March 15.	10.30 a. m.	31	13	72	0.0	44
March 16.	10.30 a. m.	29	13	72	0.0	46
March 18.	10.30 a. m.	25	12	75	0.0	48
March 19.	10.30 a. m.	24	12	76	0.0	50

Organic Nitrogen.—The amount of organic nitrogen present in sewage was determined in early days by the combustion method. Later it was estimated as twice the nitrogen in the form of albuminoid ammonia, and more recently it has been taken as three times. In preparing balance sheets recording the changes through which sewage passes when treated by various processes, it seems desirable to know more accurately than at present about the relative changes in nitrogenous matter. In Table 18 comparisons are shown between the amount of organic nitrogen determined by the Kjeldahl process and the nitrogen as albuminoid ammonia and free ammonia. The data from the several

Massachusetts cities are averages of several analyses as described in the reports of the State Board of Health for the respective years. The data from Manchester were given by Sir Henry Roscoe in his testimony before the Royal Commission on Sewage Disposal, Interim Report 1902, Vol. II, page 214.

TABLE 18.—COMPARISON OF THE AMOUNTS OF NITROGEN IN SEVERAL FORMS FOUND IN VARIOUS SEWAGES, WITH REFERENCE TO THE RELATION BETWEEN ALBUMINOID AND FREE AMMONIAS AND ORGANIC NITROGEN BY THE KJELDAHL METHOD

(Parts per Million)

	Date	Nitrogen as			Per cent. which nitrogen as albuminoid ammonia is of organic nitrogen and free ammonia	
		Organic (Kjeldahl)	Albuminoid ammonia	Free ammonia	Organic nitrogen	Free ammonia
Worcester hospital	1894	32.5	5.9	6.1	18	97
Worcester hospital	1895	32.5	5.5	7.7	17	72
Marlboro	1894	24.8	10.7	30.1	43	36
Marlboro	1894	12.6	5.5	19.4	39	26
Framingham	1894	16.7	5.9	25.3	35	23
Framingham	1895	14.5	4.3	15.7	30	27
Gardner	1894	11.2	3.1	9.5	28	33
Lawrence (fresh sewage)	1894	18.5	4.4	14.9	24	30
Lawrence (fresh sewage)	1895	21.6	5.3	13.5	25	39
Lawrence (station sewage)	1894	13.0	5.2	28.1	40	19
Lawrence (station sewage)	1895	15.8	6.1	28.1	38	22
Lawrence sewage.. 1st day	.....	39.5	8.2	20.9	21	39
Lawrence sewage.. 2d and 3d days	.....	21.3	8.7	41.3	41	21
Lawrence sewage.. 4th to 8th day	.....	16.0	7.4	41.7	46	18
Effluent of precipitation tanks at Manchester, Eng.; average of 6 analyses covering 2 weeks each: 1st set	.....	5.1	1.3	19.5	25	7
Effluent of precipitation tanks at Manchester, Eng.; average of 6 analyses covering 2 weeks each: 2d set	.....	5.3	1.4	17.5	26	8
Effluent of precipitation tanks at Manchester, Eng.; average of 6 analyses covering 2 weeks each: 3d set	.....	5.1	1.3	19.5	25	7

Carbonaceous Matter.—In connection with the "carbonaceous matter," the oxygen consumed or the oxygen absorbed is a result which is obtained by treatment with permanganate of potash in an acid solution. In some form or other it has been applied

since about 1850. The number of modifications of the process, however, is so great that there is considerable difficulty in applying the results obtained at one laboratory to the conditions elsewhere, and in all cases the results indicate only a fraction of the oxygen ultimately consumed under conditions in nature. It is the general custom in this country to make these determinations by adding acid and permanganate solution to the liquid, and boiling for a period of 5 minutes before making a titration to obtain the result. In some places, as at Lawrence, it is customary to limit this period of boiling to 2 minutes, and elsewhere the period has been 30 minutes. In Germany the period of boiling is generally extended to 10 minutes. In England, the temperature at which the liquid, after being treated with chemical solutions, is allowed to stand is 80° F., and the results are observed as to the oxygen consumed after periods of 3 minutes, 15 minutes and 4 hours, respectively. It is readily seen that the results obtained and published from such a different number of methods are bound to be variable, and to give rise to confusion in making ready deductions from the evidence accumulated at various places.

Absolute Oxygen Consumed.—It has been considered desirable for years to know the "absolute oxygen consumed," such as would indicate the total amount of oxygen necessary in order to oxidize crude organic matter completely, preferably under the conditions of nature. This is a point which has been recently studied with great advantage along lines of bacterial activity which are indicated further on in this chapter.

Any of the methods for determining oxygen consumed, if carefully carried out, gives data of assistance, especially in estimating the degree of purification effected by a process. It is highly important, however, that the method by which oxygen consumed is obtained should be recorded in connection with all important reports and analyses. If this is done, it is possible within certain approximate limits to convert the results obtained by any method into those which would be obtained by others.

Careful inquiry was made by the author in 1903 in the endeavor to ascertain factors which might be used with moderate confidence for converting to an equivalent basis the results obtained from the various methods of estimating oxygen consumed. These factors, made up of many average comparisons, are given in Table 19.

TABLE 19.—APPROXIMATE COMPARISON OF AVERAGE AMOUNTS OF OXYGEN CONSUMED BY SEWAGE AND SEWAGE EFFLUENTS AS SHOWN BY DIFFERENT METHODS

Method	Temperature of solution	Period of contact	Relative results
Kubel, as practised at Boston and generally in America	Boiling.	5 minutes.	1.00
Kubel, as practised at Lawrence, Mass.	Boiling.	2 minutes.	0.65
Kubel, as practised in Germany[1]	Boiling.	10 minutes.	1.25
English official tests	80° F.	3 minutes.	0.20
	80° F.	15 minutes.	0.35
	80° F.	4 hours.	0.60
"Absolute" oxygen consumed	Boiling.	4 hours.	4.00

[1] German results generally refer to "permanganate consumed" (oxidirbarkeit), and should be divided by 4 to give oxygen consumed.

With regard to the data used in arriving at these factors, it may be said that these comparisons between the Boston and Lawrence methods are obtained from numerous published records of the Massachusetts State Board of Health. The comparisons of the Kubel method, after heating 5 minutes and 10 minutes, respectively, are based upon very limited information which was obtained by the author a number of years ago. Comparisons of the Kubel boiling method and the official English method at 80° F. are obtained from Blair's book on "Organic Analyses of Waters," and from comparisons made some years ago in the laboratory of the late Prof. Kinnicutt, of Worcester, and communicated privately to the author.

As to the absolute oxygen consumed, the evidence was then very limited indeed, being confined to about half a dozen observations given by Blair, page 49, and by Sir Henry Roscoe in his testimony before the Royal Commission on Sewage Disposal, Interim Report, Vol. II, page 212.

Later Data.—In the 1905 Report of Massachusetts State Board of Health, page 367, Mr. H. W. Clark publishes some data indicating that a 2-minute boiling period, as compared with a 5-minute boiling period, gave the following average results:

Lawrence street sewage (fresh),	70.7 per cent.
Lawrence station sewage (stale),	76.1 per cent.
Septic sewages,	77.6 per cent.

Beginning in 1905 some laboratories have adopted the Palmer method of placing the sample under test for 30 minutes in boiling water. The 2-minute boiling test showed figures, as compared with the Palmer method, ranging from 41.0 to 77.4 and averaging 55.5 per cent. for 36 samples of sewage.

In the *Journal of Industrial and Engineering Chemistry* for October, 1911, Messrs. Clark and Adams give further data, especially for a "maximum" result obtained by putting the sample in free flowing steam. Usually about 8 hours were sufficient. The results showed that the 2-minute boiling test gave on an average 33.8 per cent. of the "maximum." But the latter gave only a part of the total carbon as determined by careful combustion tests. This percentage which the carbon required to give the "maximum" oxygen consumed was of the total carbon ranged as follows:

Unfiltered sewage,	49
Filtered sewage (through papers),	63
Unfiltered coarse-grained filter effluents,	80
Filtered coarse-grained filter effluents,	72
Sand filter effluents,	49

The lack in practical significance of the best available records of the percentage of nitrogen, carbon, sulphur and other organic constituents, will be apparent to one who knows of the immense variation in the organic character of sewage. The organic matter comes from feces, urine, kitchen wastes, laundry wastes, sweepings, stables, business houses, street washings, and manufacturing establishments. The molecular composition of organic matter from these different sources is so variable and complex that it is practically hopeless to avail of such analytical data other than for noting comparisons to a limited extent in the organic content of sewages or effluents.

STABILITY OF ORGANIC MATTER

Some portions of organic matter, particularly those in solution, are readily attacked by bacteria, as will be outlined at some length in Chapter II. Other portions of organic matter, particularly those in suspension, are attacked slowly by bacteria, or by the liquefying enzymes excreted by certain species of bacteria. In other words, sewage contains some organic matter so stable that within certain limits it is comparable with the vegetable matter

or humus found in forests beneath the carpet of leaves. This portion is of far less importance than that which has not been decomposed substantially as far as is readily accomplished in Nature's processes. It is the unstable portion, not measured by laboratory methods now in general vogue, which should receive particular attention on account of its liability to produce offensive odors.

The past few years have seen a great increase in the attention given to the amount of oxygen which sewage requires under conditions of satisfactory disposal, either when diluted in streams or subjected to biological processes in filters. It is keenly realized now that organic matter in sewage is of chief interest because of its unstable portions which decompose, "putrefy," and have a measurable relation to the consumption of oxygen under conditions found in practice. Instead of the "absolute oxygen consumed" that was sought by chemists some years ago, indicating the needed amount of oxygen from chemicals in the laboratory for the complete moist combustion of all the organic constituents, recent effort has been directed to securing the oxygen-consuming power as actually needed to provide for the proper development of bacteria with which sewage is at all times highly charged.

Incubation Tests.—The past ten years have seen a striking development in this field. It had its origin in the so-called "incubation" tests for noting the amount and character of the organic matter in the effluent of coarse-grained filters, especially as to whether the liquid would putrefy and give off bad odors after being kept in a stoppered bottle for a certain period of time at a given temperature. For about a dozen years such tests, including the rate of absorption of oxygen, have been studied at the Lawrence Experiment Station. (See 1900 Report of the Massachusetts State Board of Health, page 388.) At the Columbus sewage testing station this matter also received attention, and considerable effort was directed to ascertaining some relationship between the results so obtained and data from the regular processes of chemical analyses then in vogue. The comparative data were disappointing.

An important series of observations on the absorption of oxygen by sewage was made by Mr. H. W. Clark in his report to the Charles River Dam Committee in 1903, as summarized on pages 268–80 of the printed report of that Committee.

In a paper before the Society of Arts in 1903, the author stated the scope of the practical conditions to be reckoned with in practice, as follows:

The limitation in the amount of sewage which may be discharged into a water course without putrefaction setting in depends upon the oxygen-consuming properties of the sewage measured against the oxygen in the water of the stream, after making due allowance for the consumption of oxygen by the constituents of the water and by the matters contained on the bottom and sides of the stream.

In studying exhaustively the chemical and biological changes which take place in polluted waters, and the conditions under which putrefaction may be avoided, it is believed that the relative significance should be studied of the "absolute oxygen-consuming powers" of the organic matter in sewage or effluent expressed in terms which can be readily appreciated; of the oxygen dissolved in the sewage or effluent, together with that which may be yielded by nitrates, sulphates, and other constituents of the liquid; of the oxygen similarly contained in the water into which the sewage or effluent is discharged; of the oxygen which may be received in the water by means of aeration and from higher forms of vegetable life; and of the absolute oxygen-consuming powers of the organic matter in the water of the stream and in the sediment on the bottom and sides of the stream itself. To these factors should be added the effect of the very important items of temperature and the period of time during which biological changes may take place.

By "absolute oxygen-consumed," in the above quotation, it was the intention of the writer to refer to the amount of oxygen under conditions of nature which would be actually consumed by bacteria when they have a full sufficiency of time in which to act.

Progress along these lines lately has been substantial, largely due to the excellent work of Prof. Earle B. Phelps, who has written a separate chapter upon this subject in Water Supply Paper 229 of the United States Geological Survey. This paper deals more particularly with the stability of sewage effluents, yet its introductory pages are so clearly written that it is believed to be well worth while repeating here at some little length. Whatever the shortcomings may be of this method, it is the most practical, efficient working method now available. The advantages of having different workers follow the same method are sufficient to commend it to the most careful consideration of those in charge of sewage disposal projects involving analytical data. The full chapter by Prof. Phelps should be studied, but extracts are given below to record his viewpoint in some detail, notwith-

standing that it introduces here the subject of sewage decomposition which is discussed in Chapter II at much length.

Putrescibility.—Putrescibility, as applied to organic matter in general, implies the ability of that matter to undergo offensive putrefactive decomposition. In a strict sense putrefaction is a term applied to nitrogenous matter only, though this is a popular rather than a logical conception. Exactly what constitutes offensive putrefactive decomposition in a sewage effluent is a matter on which opinions differ. Such decomposition is always anaerobic, and it is usually accompanied by the evolution of offensive odors. These two phenomena have, therefore, formed the basis of most putrescibility tests. Some criteria of putrefaction which have been employed are: (1) Development of offensive odors; (2) formation of black sediment; (3) reduction in the amount of dissolved oxygen; (4) loss of all dissolved oxygen; (5) loss of all available oxygen, including that of nitrates and nitrites; and (6) increase in the oxygen-consumed figure. Some of these tests are based on partial reduction of the available oxygen in the effluent; others depend on the complete reduction of the available oxygen in the effluent; others depend on the complete reduction of the available oxygen and subsequent anaerobic fermentation. The tests most commonly employed belong to the latter group, depending on the production of odor or of hydrogen sulphid, blackening of the liquid, or reduction of organic dyes. The test which depends on an increase in the oxygen-consumed figure during incubation is also in that class, because anaerobic fermentation alone renders organic matter more readily oxidizable.

These two types of test illustrate two distinct points of view which should be clearly differentiated. An effluent may be regarded as being composed of a given mass of organic matter dissolved or suspended in a definite amount of water. The water contains also a definite amount of available oxygen in the form of free dissolved oxygen, nitrites, nitrates, and possibly of other compounds. All the organic matter is oxidizable to some extent, and to that extent it serves as bacterial food. The greater the amount of organic matter and the greater its oxidizability, the greater is the absorption of oxygen from the medium. Consequently a reduction of available oxygen in the effluent during incubation is a measure both of the amount of organic matter present and of its capability of oxidation. As a small amount of readily oxidizable matter has the same effect on the result as a larger amount of more stable matter, a test of this kind indicates whether or not the organic matter consumes oxygen; but it does not show whether or not the supply of available oxygen is sufficient to prevent the establishment of anaerobic conditions. This important question of the balance between the oxygen demanded by the organic matter and the oxygen available in the liquid is taken into consideration by tests of the second kind mentioned,

namely, those dependent on the establishment of anaerobic conditions. Such tests do not involve estimation of the amount and the kind of organic matter; indeed, organic matter which does not absorb any oxygen from the liquid under the conditions of an incubation test must be very highly oxidized; and, furthermore, most organic matter derived from sewage is putrescible in itself—that is, if it is stored by itself in the absence of oxygen, it undergoes putrefactive changes. The question at issue is not, however, whether the organic matter itself will putrefy, but whether the effluent as a whole will become so reduced in oxygen that putrefaction will become possible. In other words, it is simply a question of a balance between the available oxygen of the effluent and the oxygen which the organic matter will require during the incubation period. It would seem that the problem might readily be solved by determining this balance, but, unfortunately, it is not a simple matter, because the action involved is bacterial. Many attempts have been made to determine the oxygen balance analytically, but such tests answer only with very good and very bad effluents, for which an inspection of the sample would serve just as well. When there is doubt about the character of the effluent—the condition for which such information is of most value—all such analytical procedures have heretofore failed. It is evidently impossible to imitate with any degree of precision the bacterial activities that are involved. There remains, then, but one satisfactory expedient: To let the reaction proceed by itself and to note the result. But here also there are difficulties, because bacterial reactions of this sort are necessarily slow in reaching equilibrium, and the time required by a nicely balanced effluent is greater than can be allowed in routine work. Some arbitrary period of time, therefore, is usually adopted, and it is in respect to this factor that the confusion rises. If stability is to be considered a definite qualitative characteristic of an effluent, that characteristic should be determined by a test sufficiently prolonged to insure equilibrium, but such procedure is not feasible for obvious practical reasons, and it is not desirable, because it is not enough simply to know that the available oxygen is sufficient or insufficient to satisfy the demands of the bacteria that are working on the organic matter. If the available oxygen is sufficient, there is perfect stability—a definite condition; if it is insufficient, there is still stability in the quantitative sense—a relative stability determined by the relation of the available oxygen to the total amount of oxygen required by the organic matter for perfect stability. In practice the latter condition is the one usually encountered.

Relative Stability.—The term putrescibility has had so many and so varied meanings in dictionaries, in popular parlance, and particularly in the minds of water chemists, that it is proposed to employ the word stability for that desirable quality which is the usual object of sewage purification—the transformation of the organic matter to such form that

it is incapable of undergoing offensive putrefaction. This term has the added advantage of implying a positive characteristic that is acquired during purification, and it conveys a much more definite impression of the thing under discussion than the negative term putrescibility. A few more definitions are necessary in order to simplify the discussion. The time required to establish anaerobic conditions in an effluent which, on incubation in a closed bottle, is subject to bacterial activities producing such conditions may be called for brevity the reducing time; the total amount of oxygen initially present in the form of free dissolved oxygen, nitrites, nitrates and possibly other combinations may be called available oxygen; the term oxygen required to express the total amount of oxygen which would be consumed by bacterial action in the effluent if the latter were supplied with an unlimited amount of oxygen and if the reaction were allowed to proceed to a condition of substantial equilibrium. An effluent of the character under discussion is not stable in the absolute sense, because its available oxygen is less than the oxygen required for equilibrium; but, of two such effluents, that one is obviously the better which contains the greater amount of available oxygen in proportion to its required oxygen. In other words, effluents of this class have a certain relative stability which is indicated by the ratio of the available oxygen to the required oxygen. This relative stability, as will be shown, can be measured by the time required to reach the anaerobic stage. The term stability without qualification is employed in this paper to describe that condition in which the available oxygen exceeds the required oxygen, and the term relative stability is used to indicate the character of the effluent in the sense suggested. A perfectly stable effluent, therefore, has a relative stability of 100 per cent.

It is apparent that time is an important element in stability tests, and that it is not compatible with the idea of relative stability to select an arbitrary period of time for establishing the line of demarcation between stability and putrescibility. It is obviously unfair to record one effluent as non-stable because it "holds up," or fails to putrefy, for only three days and to record another as stable because it "holds up" for four days. A filter might deliver during one week an effluent that would fail to pass a four-day incubation test by a narrow margin and might deliver during the next week almost crude sewage for four days and a passable effluent for three. Obviously, the first week's run would be the better and should be so recorded; but, under the present practice in many places, all the samples during the first week would be putrescible and 40 per cent. of those during the second week would be non-putrescible. The first requisite, therefore, in logical study of the problem is that the time required for an effluent to reach a condition of anaerobic decomposition shall be taken as an index of its relative stability. This time element is absolutely indispensable, and any test that is adopted

for the determination of relative stability should be of such a character that the length of time required for the sample to reach a given anaerobic condition may be recorded.

TABLE 20.—RELATION BETWEEN REDUCING TIME AND RELATIVE STABILITY AT 20° C.

Reducing time in days (t.)	Relative stability ($1-0.794^t$.)	Reducing time in days (t.)	Relative stability ($1-0.794^t$.)
1	21	9	87
2	37	10	90
3	50	11	92
4	60	12	94
5	68	14	96
6	75	16	97
7	80	18	98
8	84	20	99

These values of relative stability are strict measures of the character of the effluent. An effluent which contains more than sufficient oxygen to establish stability should have a stability of 100; in other words, it would never reach the anaerobic stage. In practice it is necessary to set some time limit to the tests and give an average stability value to all tests exceeding this limit. This value is sufficiently high to indicate the character of the effluent. On the other hand, crude sewage containing a little dissolved oxygen is completely reduced in one or two hours, or, if it contains no dissolved oxygen, decolorizes methylene blue at once; in numerical expression its relative stability is practically zero. These figures are comparative, because they may be added and divided to obtain periodical averages and the averages thus obtained are properly weighted. This is not so if the reducing times themselves are averaged. The figures are also an approximate measure of the ratio between the total available oxygen in the effluent and the amount of oxygen required for the production of stable equilibrium in the organic matter, and it is believed that the approximation is sufficiently close for ordinary purposes of interpretation.

This method of determining stability with methylene blue, developed by Weldert and Spitta, seems to be coming into general favor. The more quickly and thoroughly it is studied at all laboratories, the better it will be, in the opinion of the author, for the advancement of our knowledge on the subject of

sewage disposal. This method was followed at the Philadelphia sewage testing station, as stated on page 28 of the 1911 report upon the results of tests made there, and also at the Chicago station, as well as elsewhere.

ATMOSPHERIC OXYGEN CONSUMED

The Royal Commission on Sewage Disposal of Great Britain considered this matter carefully, as expressed in 1908 in its Fifth Report (also Appendix VII) on permissible limits in organic matter in terms of the reduction in the oxygen content of water, as noted by incubation tests. Dr. McGowan in Appendix IV to the Fifth Report, 1910, also concluded that the strength of sewage could be best measured by oxygen withdrawn from diluted samples. We referred on page 33 to Mr. Clark's work.

Mr. Clarence B. Hoover, Chemist in charge of the operation of the Columbus sewage purification works, has proceeded along somewhat similar lines in using oxygen for measuring the strength of the local sewage. Results beginning in March, 1910, are summarized in an article by him in *Engineering News*, Vol. LXV, 1911, page 311. It is of great importance to have the results obtained from different laboratories comparable. Local customs are hard to overcome, but this difficulty will increase rather than lessen.

PHELPS' DEOXYGENATION TESTS FOR STABILITY

Still more recently Prof. Phelps, in conjunction with Col. Wm. M. Black, Engineer Corps, U.S.A. has utilized his method as described above, in testing the efficiency of aeration as reported in 1911 to the Board of Estimate and Apportionment of New York City. He has supplemented it by putting on a quantitative basis the reaction curve of the rate of deoxygenation by the organic matters in sewages mixed with oxygen-saturated water in a manner somewhat resembling but improving upon the procedure followed by Mr. Hoover. The following extracts are from the New York City Report of Messrs. Black and Phelps, pages 65–70:

Chemical Methods.—Chemical analyses have been made of the raw sewage before and after aeration and of the septic sewage after aeration. In changes in the character of the sewage with reference to its stability or its oxidizability, the ordinary methods of chemical analysis do not indicate

the significant factors. One factor of importance is the dissolved oxygen contained in the liquid in question. Of chief importance, however, is that factor which we call the stability of the sewage which is the reciprocal of its tendency to withdraw oxygen from a stream. This stability factor we have estimated in two different ways. The first is known as the relative stability method or more commonly the putrescibility. In this method the liquid is mixed with the different proportions of water containing a known amount of dissolved oxygen. A sensitive indicating dye known as methylene blue is added to the mixture and the whole is preserved in a stoppered bottle and kept under constant observation. This blue dye has the property of losing its color when the dissolved oxygen of the liquid has entirely disappeared. The time required to so decolorize a sample is a somewhat complicated logarithmic function of the stability. This function has been determined as the result of an extended series of investigations upon all classes of sewages and effluents so that we now have a well-defined relation between the time required for decolorization and the so-called relative stability. This relative stability is the ratio between the amount of oxygen available in the diluted sample and the total amount of oxygen which would be utilized by that sample in its complete oxidation. Thus a sample of such a mixture which had a relative stability of 50 per cent. would contain just half the amount of oxygen which would be required to render it perfectly stable. This method is easy of application and is the one most commonly employed in sewage work. A more delicate method for obtaining the same information, and one which was devised for this work and used here for the first time, is the following:

Suitable mixtures of the sewage in question with oxygen-saturated water are made and the total amount of oxygen in the mixture determined immediately. The sample is then stored in a tight bottle for a suitable period of time and a redetermination of the amount of dissolved oxygen present is made. The rate at which the oxygen disappears under these conditions gives us an index of the oxidizability of the organic matter and a more direct measure of the probable effect upon the stream than is given in the methylene blue method. The theoretical basis for this method will therefore be discussed in some detail.

Considering the reaction taking place between the organic matter of the sewage and the oxygen dissolved in the water, the following relation should hold:

$$\frac{dO}{dt} = KOC$$

In which O is the amount of oxygen present in unit volume, C the amount of organic matter oxidizable, d the time allowed for the reaction to proceed, and K a constant determined by the character of the organic

matter and in turn defining the oxidizability of that organic matter. Integrating,

$$\log \frac{O'}{O} = KCt$$

O' being the initial and O the final amount of oxygen present.

The constant K defines mathematically the rapidity with which the oxygen is used up in a mixture of water and sewage. It depends upon the character of the sewage matter and the concentration of that material in the sewage and is independent of the extent of dilution or character of diluting water. A value of $K = .0030$ would indicate a sewage which in 25 per cent. admixture with water would reduce the oxygen content of the mixture 50 per cent. in four hours. Similarly for $K = .0020$ the reduction in a 25 per cent. admixture in four hours would be 37.5 per cent. and with $K = .0015$, 28.5 per cent. These figures are tabulated in column A below to serve as a standard for interpreting the results of our experimental work.

In column B a set of figures are given which show the percentage of sewage of given K value which could be discharged into a stream under the condition that the oxygen of that stream shall not be reduced more than 20 per cent. in six hours.

K	A	B
.0030	50.0 per cent.	5 per cent.
.0020	37.5 per cent.	8 per cent.
.0015	28.5 per cent.	11 per cent.
.0010	20.0 per cent.	16 per cent.

A. Reduction in dissolved oxygen which would result at the end of four hours in a 25 per cent. admixture of sewage in water.

B. Maximum concentration of sewage permissible if the oxygen shall not be reduced more than 20 per cent. in approximately a half tidal period of six hours.

Chemical Analyses.—Samples were collected daily throughout most of the period covered by the work. During the latter part of the period they were collected every other day. Composite samples, preserved with chloroform, were analyzed weekly. The results in parts per million are given in Table 21 in the form of monthly averages. For comparison an average analysis of Boston sewage is given:

TABLE 21.—MONTHLY AVERAGES OF SEWAGE ANALYSES MADE ON SAMPLES COLLECTED DAILY AT EAST NEW YORK, BEFORE AND AFTER EXPERIMENTAL TREATMENT, AND AVERAGE ANALYSIS OF BOSTON SEWAGE

Month	Suspended solids			Oxygen consumed			Nitrogen as			
								organic		
	Total	Vol.	Fixed	Total	Dis.	Susp.	Free amm.	Total	Dis.	Susp.
Crude Sewage										
April	73	48	25	90	71	19	38	29	22	7
May	52	38	14	73	61	12	57	14	10	4
June	53	35	18	71	63	8	53	14	10	4
July	71	46	25	76	60	16	46	16	12	4
August	92	61	31	64	58	6	46	16	12	4
September[1]	113	86	27	76	65	11	46	28	22	6
Average:										
1st series	68	44	24	75	63	12	46	18	14	4
Grand average	75	52	23	76	63	13	46	20	15	5
Crude Sewage Aerated										
April	78	47	31	68	51	17	39	23	19	4
May	54	34	20	53	42	11	33	16	13	3
June	101	57	44	56	46	10	33	15	12	3
July	56	34	22	55	46	9	36	15	12	3
August	94	65	29	57	47	10	34	15	12	3
Average	76	47	29	58	47	11	35	17	13	4
Septic Sewage Aerated										
April	54	38	16	57	38	19	24	21	17	4
May	34	23	11	52	40	12	26	16	11	5
June	58	34	24	56	40	16	27	17	15	2
July	54	26	28	56	41	15	27	16	12	4
August	42	31	11	42	38	4	26	14	11	3
September[1]	72	51	21	49	46	3	24	25	20	5
Average:										
1st series	49	26	23	53	39	14	26	17	13	4
Grand average	51	32	19	52	41	11	25	18	14	4
Boston Sewage										
Sept.–Dec.	185	130	55	60	27	33	21	3.1	1.7	1.4

[1] Second series of experiments begun.

The high nitrogen values indicate a sewage much stronger than the average and possibly containing nitrogenous manufacturing wastes, such as brewery waste. The low suspended solids on the other hand indicate a considerable deposit in the outfall sewer. Considering the strength of this sewage, its stability is high. The sewage of Boston is fully as putrescible as this sewage, measured in terms of oxygen absorption from water, but in chemical composition it is much weaker. This bears out the indication of some relatively stable manufacturing waste. It would appear that we are dealing with a sewage which, although strong according to our analytical results is not more decomposable than an average city sewage. Improvement by aeration would, therefore, be relatively more difficult.

The analyses of the crude sewage after aeration and of the same sewage after having passed the septic tank and the aeration tank are also given in Table 21. No changes are noted other than those which can be ascribed to the action of the tanks themselves.

Relative Stability.—The relative stability results as determined by the methylene blue test are given in Table 22:

TABLE 22.—RELATIVE STABILITY, DISSOLVED OXYGEN AND PUTRESCIBILITY RESULTS AND OTHER DATA

Sewage	Period	Air, cu. ft. per gallon	Time of contact (Hrs.)	Relative stability Dilution per cent.					Putrescibility coefficient K Dilution, per cent.		Dis. oxygen
				15	20	25	30	35	5	25	
Crude	1	.....	.....	80	66	53	45	....	.0029	.0035	1.9
Crude, aerated	1	.20	1.4	95	96	77	69	61	.0020	.0020	2.3
Crude	2	.....	.....	75	57	43	.....	.....	.0054	.0060	2.8
Crude, aerated	2	.09	1.4	....	....	74	63	52	.0023	.0044	1.1
Crude	3	.....	.....	86	70	60	....	....	.0059[1]	.0040[1]	1.2
Septic, aerated	3	.36	2.8	95	95	79	61	48	.0027[1]	.0026[1]	0.34
Crude	4	.....	.....	82	68	60	....	....	.0028	.0026	2.7
Septic, aerated	4	.67	5.6	....	....	68	56	45	.0017	.0023	0.37
Crude	5	.....	.....	74	58	48	....	....	.0038	.0036	3.1
Septic, aerated	5	.77	5.6	....	....	78	70	68	.0014	.0021	1.2
Crude	6	.....	.....	79	59	44	....	....	.0076	.0104	2.5
Septic, aerated	6	.23	2.8	....	....	83	80	69	.0018	.0054	0.22

[1] These dilutions are 10 and 50 instead of 5 and 25.

This method was employed by Dr. Arthur Lederer, of the Chicago sewage testing station, in noting the extent to which the stability of sewage is modified by sedimentation and straining. In a valuable paper presented to the Havana meeting of the

American Public Health Association in December, 1911, he points out the benefit of the method, although our knowledge is lacking as to the accuracy of the reaction curve, and also indicates that with additional work upon it our appreciation of it will doubtless increase. (See the *Engineering Record*, Dec. 23, 1911, page 733.)

For years it has been known that the organic matter of sewage contains partially digested food products and other substances resembling in chemical composition the carbohydrates, proteids, fatty acids, and some other less well-known groups of organic substances. There is no way of measuring these satisfactorily by strictly chemical procedures. But their study is highly important on account of the different way in which they serve as food for the bacteria, leaving so wide a variety of results as to decomposition products and the deoxygenation of streams. Much aid should be obtained in the future by following the studies on stability of sewage in the manner outlined above.

BACTERIA

In 1894 the author computed from his studies of Massachusetts sewages that on an average city sewage contains some 320 billions of bacteria to each person connected with the sewer system. The precise number of bacteria is not of importance, as it no doubt varies tremendously at different places and at different hours. It is sufficient to say that the bacteria, the most active agents in the decomposition of organic matter, are present in all city sewages that are not distorted in their composition through the addition of acids or other germicidal waste products.

Many of the bacteria in sewage obviously are of fecal origin. The late Prof. C. A. Herter in his interesting book on "The Common Bacterial Infections of the Digestive Tract" states that the number of bacteria has been estimated at 126 billions for the daily human excreta. These are not stated as living bacteria, but the total number discernable under the microscope. Many and perhaps most of the bacteria are dead and undergoing a process of disintegration due to a solution in their own juices—a process of "autolysis." While many of the bacteria in feces may be dead, it is true that there are enormous numbers that are alive as the discharges from waterclosets enter the sewers.

They represent many species and varities, as stated by Prof. Herter and others who have given this matter careful consideration. Messrs. MacNeal, Latzer, and Kerr give 33 billions as the average number of bacteria daily found in the feces of normal adult men.

Some of these bacteria prefer certain foods that they find in sewage and multiply rapidly. Others are probably handicapped by their environment and die and gradually are disintegrated. The bodies of bacteria constitute some 20 to 35 per cent. of the total weight of the dry solid matter of feces. That is, they comprise some 20 to 35 per cent. of an average quantity estimated at about 35 grams per capita daily. A recent article by Messrs. Mattill and Hawk in the *Journal of Experimental Medicine*, October, 1911, contains instructive data on this question and also on the proportion of total nitrogen in feces which is due to the bacteria. The substance of their article may be quoted as follows:

Combining the data from both tables, the bacterial dry substance constitutes 20.05 to 35.29 per cent. of the fecal dry substance, with an average of 27.95 per cent. MacNeal, Latzer and Kerr found the variation to be from 14.03 to 42.53 per cent., with an average value of 26.9 per cent. dry bacterial substance in dry feces, a value about 1 per cent. lower than our own. The combined data show a variation of 42.6 to 62.9 per cent. for the portion of bacterial fecal nitrogen, the average value being 53.9 per cent. The investigators just mentioned found the variations in this quantity to be from 23.3 to 66.8 per cent., with an average of 46.3 per cent. While our values show smaller variations, they are uniformly higher, the average being 7.6 per cent. more than in the investigations of MacNeal, Latzer and Kerr.

Since in the determination of dry bacterial substance, a factor obtained by other investigators was used, our results upon the daily output of dry bacterial substance have not the value of original determinations, although from the uniform results of several investigators upon the nitrogen content of dry bacteria there seems to be a reasonable basis for calculation. Among the determinations of the daily excretion of dry bacteria are the following (previously mentioned):

Strasburger,	8.0 grams.
Sato,	8.54 grams.
Berger and Tsuchiya,	3.023 grams.
MacNeal, Latzer and Kerr,	5.34 grams.
Mattill and Hawk,	8.27 grams.

The data on the percentage of dry bacteria in dry feces include the following:

	Per cent.
Strasburger,	24.3
Schittenhelm and Tollens,	42.0
Lissauer,	8.67
Tobaya,	11.22
Sato,	24.39
Berger and Tsuchiya,	12.6
MacNeal, Latzer and Kerr,	26.9
Mattill and Hawk,	27.95

From results of which the foregoing form a part, it appears that the amount of bacterial nitrogen in the feces is a valuable index to intestinal conditions, and the method herein described is a simple and satisfactory one for making this determination. It involves three serial centrifugalizations of a 2-gram sample of the fresh feces brought into suspension in 0.2 per cent. hydrochloric acid. The bacterial suspension finally obtained is concentrated and extracted by alcohol, and nitrogen is determined in the precipitated material. The complete data on a given stool can be obtained in about five days, and one operator can take care of three or four stools in duplicate in one day.

On an absolutely uniform diet of simple and easily digested food during a period of three to four weeks, the average amount of bacterial nitrogen in two subjects was found to be 53.9 per cent. of the total fecal nitrogen, and this percentage, though higher than that obtained by workers heretofore, is probably more nearly a true value for bacterial nitrogen, because no ether extraction was employed.

The average daily amount of dry bacteria, calculated on the basis of the nitrogen values, is 8.27 grams.

The Columbus report of Mr. Johnson gives a number of interesting details as to bacterial contents of the local sewage. B. coli were found to average about 500,000 per cubic centimeter. Other species, the diagnostic tests of which are recorded on pages 54–5 of his report, were found as shown in Table 23:

TABLE 23.—KINDS OF BACTERIA IN THE CRUDE SEWAGE OF COLUMBUS, OHIO

Species	Number of times found
B. mesentericus vulgatus	7
B. liquidus	8
B. liquefaciens	21
B. coli communis	19
B. sporogenes	1
B. pyocyaneus	2
B. bruneus	4
B. fluorescens	2
B. hyalinus	3
B. circulans	2
B. fuscus	3
B. nubilus	2
B. delicatulus	3
B. weichselbaumii	2
B. stellatus	1
B. helvolus	1
B. cereus	1
B. cloacae	1
B. proteus zenkeri	1
B. monadiformis	1
B. aeris munitissimus	1
M. tetragenus mobilis ventriculi	1
M. casei	1
M. albicans amplus	1
M. fervidosus	1
Str. coli-gracilis	1
Str. enteritis	1
Sarcina alba	1
Ps. turcosa	1
Ps. nebulosa	1
Ps. ochracea	1
31 species.	

The work of the last 20 years in enumerating and identifying species of bacteria in sewage has not been productive of notable advances in practical knowledge. What is now needed is more precise information concerning those particular organisms which decompose sewage, in a way to interest those in charge of sewage disposal projects. More data are needed as to the life history in

sewages, as variously treated, of the bacteria which affect the cycles of carbon, nitrogen, sulphur and phosphorus, and of other biological processes. This is also true of larger organisms, such as molds and other forms both of plant and animal life.

As related to sewage disposal, the field of sanitary biology seems now to be disappointingly shallow and narrow in some respects. The subject is complex and associated with physics and chemistry, in some of its phases, so as to make difficult the solution of questions that are now obscure. Present conceptions of biochemistry of sewage disposal need overhauling and extending. They do not seem to be so generally abreast of the times as are developments along corresponding lines in the fields of agriculture and scientific medicine.

From the above comments it is not to be inferred that chaos prevails as to the biochemistry of sewage. It is true, however, that full advantage is not generally taken of present information on basic principles, in exemplifying theory on which practice should be founded. But in order to go deeply into the subject the reader should consult some recent work on applied "bacteriology." Prof. Marshall's book, "Microbiology for Agricultural and Domestic Science Students," will be found helpful. Twenty contributors collaborated in its preparation. It came to the attention of the author after much of the theoretical part of this book was in press.

RÉSUMÉ

Sewage varies tremendously in its composition at different hours in the same sewer. The rate of flow in the same sewer also varies. In different cities there is a wide variation in the composition of sewage, particularly due to the influence of street washings and industrial wastes.

The results of a few scattering analyses are apt to be distinctly misleading. On the other hand, caution is required in drawing conclusions as to the data on sewage composition at one city being applicable to conditions elsewhere. Local data are highly desirable. Considerations of changes in sewage composition in future make it important to compare estimated data of a given project with available information from other sources.

Solid matters in suspension which make sludge or scum, unstable organic matters which deoxygenate water and affect rates of filtration, and bacteria which relate to decomposition and

disease, are the principal constituents of sewage of practical significance.

Methods of measuring organic matter, as albuminoid ammonia; Kjeldahl nitrogen or oxygen consumed, have some advantages for comparing results where full records for long periods are available. Such data are also of aid in making some special comparisons. But, generally speaking, the results of such tests are a disappointment, as they show but little as to the character or source or deoxygenating properties of the organic matter, and about which knowledge is needed for the advancement of the art of sewage disposal.

The recent efforts of Prof. Phelps, to determine the equation of the reaction curve between available oxygen and the putrescible matter in crude sewage and other liquids, mark a prominent step in the direction of improved records of sewage composition. While the work of Prof. Phelps and Dr. Lederer indicates that present knowledge as to this curve needs extension in order to establish a more correct formula, the method is undoubtedly a distinct step in advance and should receive careful attention in all important investigations.

The deoxygenating power of sewage varies with the age of the sewage due to bacterial decomposition. In small sewerage systems atmospheric oxygen coming from the water supply is still present in the sewage at the outlet. In the sewage at the outfall of large sewage systems, on the other hand, dissolved oxygen is ordinarily absent.

The physical character of suspended matter varies with the age of the sewage as the particles in suspension become comminuted by flow.

Bacteria of a harmless character are the principal agents effecting the decomposition of sewage. The field of biochemistry is of importance in the advancement of our knowledge of sewage disposal. While information at present is meager in some respects and needs extension, it will be distinctly helpful in the consideration of disposal projects to study them carefully in the light of present biochemical data.

CHAPTER II

AEROBIC AND ANAEROBIC DECOMPOSITION OF SEWAGE

Sewage is composed of a wide range of organic substances. It includes various excretions from the human body with digested and partially digested food voided from the abdominal tract, together with other organic substances coming from various wastes of the household. In some instances it contains numerous other organic substances from industrial wastes, street wash, etc. Quite important for present purposes is the presence in sewage of bacterial flora from the intestinal tract of man as well as other sources.

It is the bacteria which are chiefly instrumental in bringing about the decomposition of organic matter. Just how they effect their work is not clearly known in all of its detail, although a vast fund of information is now available in the field of applied bacteriology with respect to sanitary as well as medical science. Progress has been made steadily during the past half century since this subject was placed on a substantial foundation by the classical researches of the late Louis Pasteur. His researches into the fermentation and decomposition of organic matter led him to the conclusion clearly set forth by Woodhead on pages 68–9 of his book on "Bacteria and Their Products," as follows:

> These researches eventually led Pasteur to the conclusion well stated by Duclaux, that 'whenever and wherever there is decomposition of organic matter, whether it be the case of an herb or an oak, of a worm or a whale, the work is exclusively done by infinitely small organisms. They are the important, almost the only, agents of universal hygiene; they clear away more quickly than the dogs of Constantinople or the wild beasts of the desert, the remains of all that has had life; they protect the living against the dead; they do more: if there are still living beings, if, since the hundreds of centuries the world has been inhabited, life continues, it is to them we owe it.' Without them the surface of the earth would be covered with dead organic matter, the remains of plant and animal bodies, which, retaining the elements necessary for the building up of new plant life and animal bodies, would soon cut off the food supply of new plants and animals; life would be impossible because the

work of death would be incomplete, or, as Pasteur puts it, 'because the return to the atmosphere and to the mineral kingdom of all that which has ceased to live would be totally suspended.'

CLASSIFICATION OF BACTERIA

Without going deeply into the subject of bacteriology it seems desirable, in order to understand the importance of bacteria in sewage disposal, to appreciate some of their different classes and groups with respect to the processes under discussion.

These minute cells 1/10,000 to 1/25,000 of an inch or so in size, belong to the vegetable kingdom and are generally classified on broad lines as saprophytes or parasites. Saprophytes are those which live upon inanimate matter, and parasites are those which live upon the substance of animate bodies. Parasitical bacteria are further spoken of as being either obligatory or facultative parasites. The former thrive only upon the juices and tissues of living bodies, while the latter exist either upon living or dead matter. Saprophytes might similarly be classified. Thus the ordinary bacteria of the air, water and soil are classed as obligatory saprophytes, while such disease germs as those of typhoid fever, Asiatic cholera, etc., may be termed facultative saprophytes, since they can be grown on certain media in the laboratory and in nature continue to live usually in diminishing numbers, when eliminated from the living tissue upon which they thrive and perform their specific functions.

RELATION TO OXYGEN

Bacteria show a striking classification with respect to their need for free oxygen. The best known bacteria are those spoken of either as obligatory aerobes, which require free oxygen in order to live, or as obligatory anaerobes which do not grow except in the substantial absence of free oxygen. Facultative anaerobes are those that can live either in the presence or absence of oxygen.

This classification was effected by Pasteur about 50 years ago and has stood the test of time with regard to its substantial accuracy in practical bacteriological studies. The only point worth mentioning is that recent studies show that the anaerobes require the presence of very minute quantities of oxygen in order to perform their metabolic activities. It seems to be the concensus of opinion that the anaerobes do not require the pres-

ence of free oxygen, but that they can secure what little they require from the breaking up of the organic substances upon which they live.

RELATION TO KIND OF FOOD

For a long time it has been known that certain groups of organic substances serve as a particularly suitable food for certain species of bacteria. In fact, they serve as diagnostic tests in the laboratory. Some bacteria will effect certain kinds of decomposition of carbohydrates and others will not. The same is true of proteids which is essentially a nitrogenous product. Similarly some forms of life thrive on sulphur compounds.

The processes of fermentation and putrefaction are intimately associated with these characteristics. Much confusion seems to exist, however, as to their nomenclature and, in a lesser degree, to their significance.

FERMENTATION AND PUTREFACTION

Fermentation and putrefaction will be considered here in accordance with the definitions of those expressions by the late Prof. C. A. Herter as given on page 214 of his book on "The Common Bacterial Infections of the Digestive Tract":

It is helpful to review the fermentative and putrefactive processes in the digestive tract of man from the standpoint of their products, although such a course may somewhat temper enthusiasm by revealing our ignorance in many important directions. I shall use the word 'fermentative' to designate the decompositions of carbohydrate and fatty substances and the word 'putrefactive' as applied to the cleavages of proteid and allied substances. The distinction is important, for while the products of fermentation are in themselves usually unimportant as agents of intoxication, the products of putrefaction include substances containing sulphur or nitrogen or both sulphur and nitrogen, and thus frequently derive a chemical basis for exerting toxic effects. While making this distinction, however, I do not lose sight of the fact that fermentative and putrefactive processes overlap in the sense that they furnish some products in common, such as carbon dioxide and volatile fatty acids; they are moreover closely linked by the fact that excessive fermentation in the digestive tract nearly always leads to excessive putrefaction, for reasons which I hope to make clear.

The best discussion of this subject is to be found, in our opinion, in the article by Dr. Arthur I. Kendall on "Certain Fundamental Principles relating to the Activity of Bacteria in the Intestinal

Tract: Their Relation to Therapeutics," appearing in the *Journal of Medical Research* for September, 1911, pages 117–87. Omitting references to the extensive bibliography, this discussion is quoted from pages 138–45, as follows:

Fermentation and Putrefaction.—It will be essential to define clearly just what is meant by fermentation and putrefaction. Two most fundamental types of bacterial activity are expressed by these terms, which are in reality essentially distinct, although they have been greatly confused, and used synonymously by the laity and even by professional men. This confusion is attributed partly to the use of terms to designate certain processes which occur in nature before these changes were studied either biologically or chemically.

In reality, fermentation and putrefaction are generic terms, indicating respectively microbic activities upon two entirely distinct types of organic compounds, the carbohydrates (and closely related compounds) and the nitrogenous bodies. It is very probable there are groups of substances intermediate between the carbohydrates and nitrogen-compounds referred to, in which it would be difficult to predict a priori just how definite types of bacteria would react, and, indeed, such is probably the case. This does not, however, militate against the correctness of the general theory that fermentation and putrefaction are entirely distinct processes, but rather emphasizes the fact that bacteria are reagents far more sensitive than those commonly used in chemistry. Turning now to a separate discussion of fermentation and putrefaction, we will first discuss the former.

Fermentation.—Fermentation is probably the earliest example known to science of the application of microorganisms to accomplish a definite purpose. The fermentation of grape juice to wine was a process known to remote antiquity so far as the results were concerned, and even today, although the organisms concerned are fairly well known, the process is not essentially different from that known to the ancients. The essential feature, the action of yeast upon carbohydrate to form alcohol, is a typical example of a fermentation.

It is known, however, that various yeasts possess the power of forming alcohol from various sugars, and, indeed, even bacteria may accomplish the same end, thus indicating that fermentation is a much more general phenomenon than the mere action of yeasts upon sugars.

Coincidently with this production of alcohol from sugars, other products are formed, even by yeasts, although certain of these latter substances are formed in very minute amounts, so that their presence is rather suspected than demonstrated chemically. These secondary products, both those formed in minute quantities, and those more tangibly present, again indicate strongly that fermentation is a more complex process than would appear at first sight, even if it is brought

about by but a single "species" of yeast. Without going into details, the effects of various yeasts, and bacteria, upon various carbohydrate media make it apparent that fermentation is a rather general term embracing a variety of phenomena. In other words, fermentation must be used in a generic sense, and it is now possible to distinguish various types of fermentation, brought about by the activities of different kinds of microorganisms: we recognize alcoholic, lactic, acetic and other fermentations. The use of the term fermentation in the generic sense does not indicate a loss in dignity or comprehensiveness; indeed, it actually gains in importance through the recognition of its more general application.

Alfred Fischer has defined fermentation in the broadest sense, and his definition leaves little to be desired, being straightforward, definite, and comprehensive. "Als Gärung soll hier nach dem Beispiele vieler Autoren, die biochemische Zersetzung stickstoffreier organischer Verbindungen, besonders der Kohlehydrate durch besondere Gärungserreger, Fermentorganismen bezeichnet werden."

It is very probable that Fischer did not separate two very distinct processes which occur in practically every fermentation: the destruction of carbohydrates, containing no nitrogen, and the metabolism of nitrogenous substances which all microorganisms need in their dietary. This distinction between the very note-worthy breakdown of carbohydrates (which is the salient feature of every fermentation) and the limited, and usually not recognized nitrogen metabolism by the fermenting organisms is of great importance, and, as will soon be shown in the discussion of putrefaction, a similar distinction is to be made there. In putrefaction, where the action of the microorganisms concerned is limited sharply to nitrogenous substances, it is very difficult to distinguish between the widespread breakdown of protein, the essential feature of the process, and the very limited utilization of protein for purely dietary purposes.

Turning now to the definition of fermentation, in the light of what has been said above, fermentation may be defined as "the action of microorganisms upon carbohydrates." This is a very general definition, and covers the salient feature of the process, the action of microbes upon carbohydrate. In order to specify the particular type of fermentation under consideration, the terms lactic, acetic, etc., are utilized.

Putrefaction.—The wildest confusion exists concerning the essential features of putrefaction. The term has been used as a synonym for fermentation, and in supposedly authoritative dictionaries and encyclopedias, even to this day, the terms are thus confused. The popular conception of putrefaction associates this condition with the generation of foul odors, and many scientists adhere to this conception as well. To this association of foul odor, many add the necessity of anaerobic conditions. This definition of putrefaction being associated with the elaboration of foul odors under anaerobic conditions is based upon intangible

evidence, for it is impossible to discuss odors, foul or otherwise, in measurable or even definable terms, strictly speaking. A striking example of the correctness of the contention that putrefaction is not as simple an entity as the definition would indicate is shown by the fact that indol and skatol are not as a rule formed by the action of anaerobic bacteria, at least in appreciable amounts. Indol and skatol certainly are to be classed with the "foul odors," and suggest the essence of putridity, yet it is a singular fact that anaerobic bacteria (which are supposed to be the *sine qua non* of putrefaction) form them only in minimal amounts, indeed, many anaerobes, including B. putrificus, do not form them at all. On the other hand, bacteria of the facultative type, as, for example, B. coli and B. proteus, form indol in considerable amounts under favorable conditions. Yet the majority of authorities would not classify these organisms as typical putrefactive bacteria, nor would they admit that they could initiate and carry out a typical putrefaction. Hydrogen sulphide is another moderately vigorous odor, foul, and suggestive of putridity; it may be produced in relatively large amounts by bacteria not putrefactive in the regularly accepted sense. Bienstock and his co-worker Wollach were among the first to study putrefaction from the standpoint of the organisms concerned, and they were inclined to believe that true putrefaction was brought about by a single organism, an obligate anaerobe, B. putrificus. Other workers in this field, following their lead, have made similar declarations, until at the present time the opinion is widespread that this organism, together with possibly one or two other obligate anaerobes, are the true agents able to bring about putrefaction. According to Bienstock, B. putrificus forms NH_3, H_2S, peptone, amino bases, valerianic and butyric acids, leucin and paraoxyphenylpropionic acid. It is a significant fact that not one observer has detected indol or skatol among its decomposition products. Yet Bienstock and his school believe these latter substances are very typically found in putrefaction, in the restricted sense in which they define putrefaction.

Nencki, Kerry and Zoja, have specially studied the chemistry of B. putrificus, and they have also found that it produces no indol or skatol. Seelig and Dauber have found that while B. putrificus forms no indol, organisms commonly associated with it in natural putrefactions, as for example B. coli and B. proteus, form indol in peptone containing media, and they believe that the obligate anaerobe breaks the native protein to the peptone stage, where the facultative anaerobes take up the work and carry the decomposition through the indol stage to lower and simpler compounds.

Indol and skatol represent somewhat advanced decomposition of protein substances, and it appears to be a fact that anaerobes as a class do not bring about enough action upon the protein molecule to reach the indol and skatol stage. In fact, anaerobes, generally speaking, bring

about a merely superficial, but widespread destruction of protein, contrasting in this respect with the facultative anaerobes, which take the initial products formed by the anaerobes to their lowest terms. Hueppe recognized this distinction in action between anaerobes and aerobes as early as 1888: "The changes induced in the substratum by anaerobic bacteria differ from the changes taking place in the presence of free oxygen. The maintenance of life without free oxygen depends solely upon the availability of compounds from which oxygen may be split off. The amount of chemical change, therefore, is relatively much less intense than in anaerobic conditions: Thus, if one thousand grams of sugar be completely oxidized to CO_2 and H_2O in the presence of free O_2, 3939 calories of heat units are produced. If, however, it is split into butyric acid, H_2 and CO_2, only 414 calories are produced. It follows, therefore, that anaerobic bacteria must superficially disintegrate a far larger quantity of material to obtain this necessary oxygen than aerobic bacteria, a circumstance that has considerable significance in the large production of toxins by organisms growing in the living body."

In nature, at least (and it is here that the conception and term putrefaction arose), the phenomena grouped together as putrefaction represent a series of symbioses in which the initial, superficial breakdown is brought about by the anaerobes, while the process is carried to its lowest terms by the facultative anaerobes. Certain Germans have dimly recognized that putrefaction is indeed more than a simple anaerobic decomposition, and without knowing definitely the steps involved, they have made a distinction between "Fäulnis," putrefaction in the popular sense, and "Verwesung," which apparently is synonymous with Eremecausis, or the terminal stages of nitrification as we know them in the presence of free oxygen, moisture and the activities of many kinds of bacteria.

The principal difficulty met with in defining putrefaction appears to be that the process has been named without knowing much about it. In order to bring out this contention distinctly, a few definitions of putrefaction are appended. They have been gathered from what ought to be authoritative sources:

Flügge. By putrefaction, or putrid fermentation, one understands the rapid and intensive dissociation of nitrogen-containing, chiefly protein, substances by certain bacteria, through which process gaseous, offensive products are produced in considerable amounts.

Migula. Putrefaction: the decomposition of animal or vegetable substances without regard to their chemical properties.

Cornil et Babes. Putrefaction must be considered as the process and result of different fermentations which vegetables and animals undergo after their death. Fermentations of nitrogenous substances are naturally the most important to recognize in the phenomena of putrefaction.

Gunther. Fäulnis, putrefaction: the anaerobic decomposition of

protein, with the production of foul smelling products. Verwesung (eremecausis): an oxidization process, with free access of air; a very important factor in the self purification of the soil.

Kolle und Haetsch. Certain anaerobes break down nitrogen-containing organic compounds in a definite manner through a series of reductions resulting in the formation of volatile and non-volatile compounds, many of which are foul smelling.

Encyclopedia Britannica. Putrefaction: the scientific meaning of this term coincides pretty much with its popular conception, except that it must be understood to be exclusive of all forms of oxidization.

Standard Dictionary. Putrefaction: the act or process of putrefying, decomposition of vegetable or animal matter, accompanied by fetid odors; now regarded as a sort of fermentation or breaking up of complex organic compounds into simpler compounds produced by the micro-organisms called putrefactive ferments.

With such a variety to choose from it would appear to be time to define putrefaction in a logical manner.

Putrefaction, reduced to its lowest terms, is a generic term quite similar in this respect to fermentation. The phenomena involved are much more complex than those of fermentation because the nitrogenous substances involved are, or may be, far more complex than the carbohydrates. The wide range of intermediary breakdown products contrast in a noteworthy manner with the simpler and more direct transformation of carbohydrates, and the very fact that there is such a variety of intermediary compounds presupposes in nature a multiplicity of bacterial "species" to bring about the transformation of the complex to the simple.

At first sight it might seem to be a very difficult if not impossible task to formulate a definition of putrefaction which should be specific enough to sharply define the process to a definite type of microbic activity, and yet general enough to attain the necessary degree of comprehensiveness. It is possible, even in the face of our present comparative ignorance of the chemistry of putrefaction, to formulate such a definition.

Fischer has again grasped the salient feature of putrefaction, and his definition is well worth considering: "Sie (Fäulnis) ist demnach die Zersetzung stickstoffhaltiger Produkte des Tier- und Pflanzenlebens besonders der Eiweisskörper durch Bakterien."

By putrefaction, then, is meant the bacterial decomposition of nitrogenous substances. This definition is a generic one, precisely as the definition for fermentation given above was a generic one, and it may be qualified in precisely the same manner that fermentation may be qualified. As our knowledge of putrefaction widens, doubtless many types of putrefaction will be recognized.

In the last analysis, both putrefaction and fermentation are enzyme

phenomena, differing but slightly from the digestive processes in man; the terms, however, must be specifically limited to the action of microorganisms or enzymes elaborated by microorganisms.

The necessity for distinguishing sharply between fermentation and putrefaction is by no means an academic one; the two phenomena are fundamentally different and diametrically opposed. Together they represent the most fundamental phenomena of bacterial metabolism.

It will now be possible to enter into a discussion of the significance of putrefaction and fermentation respectively. It was stated in preceding paragraphs that for the most part the studies upon the intestinal bacteria have led to little that is definite concerning their modes of action, their significance and their relations to their host. These purely academic studies upon bacterial morphology, while necessary, are after all studies in differences (more or less trivial for the most part) between closely related forms; the problem of intestinal bacteriology is much more a study of relationships and biochemistry than of differences of morphology and physiology. The most satisfactory manner of approaching the problem of bacterial relationships in the alimentary canal is to realize at the start that these organisms depend upon the food of their host for their sustenance and their very existence. Consequently, it should be a comparatively simple matter to vary the food of the host in a definite manner, and observe the character of the bacterial response to these dietary changes. This has been done by the writer, and the results obtained will be referred to briefly, because they illustrate the differences between putrefaction and fermentation in a manner not appreciated when these experiments were published.

CLASSIFICATION OF DECOMPOSITION PROCESSES

It follows from what is said above that organic matter is broken down into simpler substances through the activities of the bacteria. Bacterial decomposition, in some instances, takes place in the presence of oxygen and is properly spoken of as an aerobic or oxidizing decomposition. Such modifications in the organic contents of sewage and other organic substances are effected, of course, by the aerobic bacteria, either facultative aerobes or obligatory aerobes.

In the absence of free oxygen, organic matter is also decomposed, but in this instance by the anaerobic bacteria. Such action is properly spoken of as an anaerobic or reducing decomposition.

Hitherto it has been quite a general custom to speak of an aerobic decomposition as "fermentation"; and of anaerobic decomposition as "putrefaction." The latter expression is in

such general use, and in the minds of many persons is so closely related with the foul odors of decomposing organic matter, that it will be difficult to restrict its use to the proper lines set forth above by Herter and Kendall. The correct use of these expressions, however, will do much to facilitate a proper understanding of the subject. Undoubtedly sewage contains substances which are acted upon by true fermentation, and true putrefaction, respectively.

Many of the sewage bacteria are of intestinal origin and come under the facultative class that adapt themselves to growth either in the presence or absence of oxygen. It is possible to conceive that some suspended matters, such, for instance, as particles of feces, may contain bacteria which are thriving as anaerobes, although the particles of feces may be surrounded with water from which the dissolved oxygen has not been exhausted by the aerobic bacteria growing therein. As a general proposition, however, it may be said that bacteria in sewage or a sewage effluent proceed either upon an aerobic or anaerobic basis. By that is meant that sewage decomposes through an oxidation or aerobic process so long as oxygen is available either from atmospheric oxygen, nitrates or any chemical compound which will release free oxygen. When oxygen becomes exhausted the bacterial flora adjust themselves to the new environment and the anaerobic bacteria proceed with the reducing or anaerobic decomposition.

One of the most important observations ever made at the Lawrence Experiment Station was a demonstration of the fact that so long as some oxygen is present at all places and at all times within a filter, oxidation processes, due to bacterial action directly or indirectly, proceed as effectively, or nearly so, as if the filter were provided with a great abundance of atmospheric oxygen instead of only a small (1 to 3 per cent.) supply. (See Special Report, Massachusetts State Board of Health, 1890, Part II, page 734.)

ENZYMES

It was once believed that bacteria effected the decomposition of various substances by the direct action of the living cells. Now it is known that many and perhaps most of the processes of disintegration by bacteria are brought about by soluble ferments called enzymes. These substances, serving as auxiliaries to the

action of the living cells, are diffused from the cell and exert their action upon the surrounding substances with which they come in contact. For the purpose of indicating the part that the bacteria play in the decomposition of sewage, it is probably needless to say more as to distinguishing between cell action and the action of enzymes or soluble ferments. It would be helpful, however, if we had more definite information as to the time interval required for the production of effective quantities of enzymes.

CONDITIONS CONTROLLING BACTERIAL GROWTH

This is a broad field which will be touched upon but lightly in order to show how these minute organisms from about 1/10,000 to 1/25,000 of an inch in size are materially affected by their environment. Their growth is measurably influenced by temperature, by the nature of the food in which they live, and the extent of the acids or alkalies with which they come in contact.

In the decomposition of sewage, considerable influence may be exerted upon each other by the different species of bacteria which are working together. This opens up a large subject and reference will be made but briefly to symbiosis and bacterial antagonism.

By symbiosis is meant the beneficial effect produced upon certain species of bacteria when other species live beside them. That is, certain functions of the bacteria, as found in the decomposition of complex organic substances, are much enhanced by the presence of certain other kinds of bacteria. Some of the effects of symbiosis are quite striking, but it is enough for present purposes simply to indicate that this is a factor to be borne in mind, and one which may explain quite frequently conditions and results that otherwise would seem most puzzling.

Bacterial antagonism or antibiosis is, of course, the opposite of symbiosis and refers to the retardation of growth and perhaps the death of bacteria under certain environment due to the presence of other species of bacteria or their life products. When bacterial growths come to an end in sewage and sewage effluents, it is not ordinarily because of lack of food, but for the reason that their environment becomes unfavorable owing to the amount of acid or other by-products that are secreted by bacterial cells in the process of their growth. In other words, bacteria come

within the scope of that rule so generally applicable to living matter, namely, that life comes to an end when the growing organisms are not freed in their surroundings of the products of their own growth.

To the laboratory observer, this may be well illustrated by a series of simple experiments, such, for instance, as the continuance or discontinuance of the fermentation of various carbohydrates, depending upon artificial changes either in the acidity or alkalinity of the culture media. Another simple observation noted in the early days of the Lawrence Experiment Station was that the boiling of ordinary river water caused it to serve as a medium for prolific bacterial growth, far beyond the limits of any bacterial growths noted in the unboiled water in question. This is detailed in the 1890 Report of the Massachussetts State Board of Health, Part II, page 593. The explanation of the boiling experiments with Lawrence water is doubtless associated with the destruction of products of decomposition that are unfavorable or inhibitive to bacterial growth.

Bacterial antagonism and toxic products are doubtless of prime importance in explaining the fact that the specific germs of certain intestinal diseases, such as typhoid fever, not only do not multiply in natural waters, but will live, as a general proposition, for the shorter period of time in those waters which contain the greater amount of organic matter and the greater bacterial flora.

BEHAVIOR OF ORGANIC MATTER IN WATER

Bacterial action effects the decomposition of practically all kinds of organic matter present in water. Different species of bacteria, different constituents in the organic matter, and various other differences, particularly as to the presence or absence of oxygen, influence powerfully the manner of decomposition and the products resulting therefrom.

The decomposition of organic matter as found in swamps and particularly as stored in impounding reservoirs in connection with municipal water supplies, has been made the subject of numerous investigations and affords a substantial clue to some features of the decomposition of sewage. This is particularly true with respect to the experiences in the decomposition of stored waters and the production of objectionable tastes and odors. Indeed the insight which the author has in the matter of decomposition under oxidizing and reducing conditions was much

enhanced in 1906–07 when Mr. Allen Hazen and he were engaged in studying the merits and advantages of stripping the sides and bottom of the large impounding reservoir in the Catskill mountains for the new water supply of New York City. These investigations led to a careful study of all available literature and the more notable experiences in the storage of water, not only in this country but abroad. In conjunction with this chapter on Sewage Decomposition, it is believed that it may be of interest to read the report on the New York City reservoir projects, as set forth on pages 181–255 of the 1907 Report of the Board of Water Supply of New York City.

Mention may briefly be made here of several summaries of the writings of the late Profs. Wm. Ripley Nichols and Thomas M. Drown, each of whom during his life time occupied a foremost rank as chemist and sanitarian. Furthermore, these gentlemen, acting in turn as chemical advisers to the Massachusetts State Board of Health, had unusual opportunities for studying these and other similar matters.

On pages 185–87 of the report of the Board of Water Supply of New York City for 1907, a summary is given of Prof. Nichols' views on the decomposition of organic matter, taken from his book, pages 84–9, on "Water Supplies," published in 1883.

SUMMARY OF PROF. NICHOLS' VIEWS ON DECOMPOSITION

A word or two may be in place with reference to the action of fresh water upon vegetable matter in its bearing upon impounding reservoirs. When vegetable matter decays in moist soil, it is converted into a brown or black substance generally known as "humus"; this is really a mixture of a number of different bodies, and from it chemists have isolated a variety of substances, such as humic acid and humin, ulmic acid and ulmin. The acids of the humus, by oxidation, undergo chemical change, to be sure, being converted into crenic or apocrenic acids which, or rather the salts of which, are found in surface waters; but when the vegetable matter is thoroughly "humified," as in the case of peat, it exerts apparently no bad effect on the water, except by giving it a brown color and a somewhat earthy taste.

When a recently felled tree is exposed to the action of the water, or when bushes or even grass and weeds are killed by being flooded with water, the sap and more soluble matters are bleached out and putrefy, or, in the presence of much air, undergo other forms of decomposition. This action will take place, no matter under what depth of water the

vegetable matter may be placed, but the effect will be less marked as the amount and motion of the water is greater.

After the more soluble portions are extracted, the subsequent decay proceeds with extreme slowness, provided the remaining cellulose or woody fiber is kept continually covered with water, but alternate exposure to the air and water soon causes decay, as every one knows. In a natural or artificial reservoir the inevitable variations of level are very disadvantageous. As the level is lowered those aquatic plants which grow in shallow water die, and if the water rises after only a short interval it becomes impregnated with the products of their decay; if a considerable interval elapses, land plants grow upon the exposed surface, and, being drowned by the rising waters, tend to its contamination in the same manner.

It appears from this, that in the construction of impounding reservoirs, the mass of growing plants, as well as the soil in which they have their roots, and which of itself contains more or less soluble organic matter, should be removed as thoroughly as possible, especially if the water is to be of no great depth above it when the reservoir is flooded. If the reservoir is filled without such removal of the organic accumulations, a long time may be required before the chemical changes have completed themselves and the water becomes well suited for use; but the complete removal of the soil, as far as such removal is practicable, is not a guaranty that no trouble will arise from a newly filled reservoir. Occasionally the vegetable decay in a new reservoir gives rise to much offense in the formation of sulphureted hydrogen. A marked instance of this occurred in one of the basins of the Sudbury river supply, Boston, Mass., the summer after it was first filled. The whole mass of water in the basin was permeated with the odor, which was so strong on the leeward side of the pond as to incommode the passersby. The odor was not that of pure sulphureted hydrogen as prepared in the laboratory, and the gas was no doubt accompanied by other chemical products. The water drawn from the depths of the pond had the odor of an antiquated privy. The presence of sulphureted hydrogen was made very manifest by suspending in the gate-house cloths wet with a solution of acetate of lead; these became yellowish-red and finally jet black, owing to the formation of sulphide of lead.

The formation of the sulphureted hydrogen is readily explained. The flooding of the basin started the decay of a large quantity of organic matter; this taking place in the presence of sulphates contained in the water changed them into sulphides and from these sulphides thus formed sulphureted hydrogen is liberated by the acid products of decay. This same change takes place to a less degree in almost all ponds and reservoirs. The gas is formed, however, mainly at the bottom, and as it diffuses upward and mixes with the overlying water it comes into contact with the oxygen in the water and is decomposed. The sulphur

is set free and sinks to the bottom, or in a very finely divided state flows off with the water . . . .

These algæ, when present in any considerable quantity, give a repulsive appearance to the water, and when they are in a state of decay they communicate to it an offensive taste and odor. Fortunately, in most cases, the trouble which they cause is of short duration, although often recurring in the same water supply year after year. Their presence is not a sign of contamination, as they occur in natural ponds removed from all polluting influences. While, however, they do grow in pure waters and in old and clean ponds, they seem to grow more abundantly in water containing mud and vegetable extractive matter, as in newly filled reservoirs; so that, while immunity from their presence cannot be guaranteed in the case of any pond, they may with some certainty be looked for in dirty and especially shallow ponds. A warm temperature and shallow water are perhaps of even more importance than the products of decay of higher plants, for all surface waters contain the ammoniacal and mineral salts necessary for the growth of the algæ.

As far as our present knowledge extends, there is nothing that can be done to exterminate the algæ from ponds in which they occur . . . .

With reference to the minute organisms, animal and vegetable, it is a curious fact that certain forms will sometimes suddenly appear in places where for years previous they have never been known to occur, and they may disappear as suddenly as they came. In other cases, forms which have been known to be present to a limited extent will increase enormously, owing to conditions of which we are quite ignorant.

SUMMARY OF PROF. DROWN'S VIEWS ON DECOMPOSITION

From 1888–95 Prof. Drown made some notable studies with respect to the decomposition of organic matter and in the New York Report, pages 193–4, a summary of his principal conclusions, as stated in the reports of the Massachusetts State Board of Health, is given, as follows:

Waters containing organic matter in the presence of oxygen are decomposed by bacterial action and in this oxidation the carbon and the hydrogen of the organic matter take precedence over the nitrogen (1891 Report, page 386). Objectionable tastes and odors seldom result from this decomposition of organic matter in the presence of oxygen (1891 Report, page 380). The measure of this change in organic matter was taken as being indicated by the free ammonia.

Where oxygen becomes exhausted the organic matter in water is subjected to the activities of other kinds of bacteria. Such waters are spoken of as "stagnant" and the bacterial process which stagnant waters undergo is spoken of as "putrefaction." Resulting from the putrefaction of organic matters, stagnant waters possess offensive odors,

due largely to sulphureted, carbureted and phosphoreted hydrogen (1891 Report, page 381).

The stagnation of water is stated not to be objectionable in itself, and a practical suggestion of much merit is made with regard to the correction of the offensive odors from stagnation by means of aeration (1891 Report, pages 380–4).

The several reports made it plain by inference that the objectionable tastes and odors of stagnant waters are due to gases of decomposition and not to growths of organisms. In fact, recent evidence makes it appear that the fungi are only organisms capable of growing prolifically in stagnant water and they do not directly cause objectionable tastes and odors.

Stagnant waters are improved by aeration, partly by the mechanical removal of objectionable gases (1891 Report, page 392) and partly by the oxidation of dissolved compounds, especially salts of iron (1891 Report, page 381).

The opinion was restated that the character of the bottom of reservoirs affects stagnation and putrefaction of the water therein contained, more than does the dissolved and suspended organic matter in the water itself (1892 Report, page 341).

Cases were noted where reservoirs contained stagnant and offensive bottom layers in which the amount of organic matter was less than in the top water when the latter contained both oxygen and organic growths producing seriously disagreeable odors (1892 Report, page 339).

CONDITIONS UNDER WHICH DECOMPOSITION TAKES PLACE

Before dismissing the general subject of decomposition of organic matter, as the lessons have been learned from water supply experiences, it will be well to reiterate for the sake of explicitness the fundamental importance of keeping in mind that decomposition takes place under two quite different conditions.

Aerobic bacteria in the presence of free oxygen effect an oxidizing decomposition, while anaerobic bacteria in the absence of free oxygen effect a reducing decomposition. The former produces few or no objectionable odors of decomposition, whereas offensive odors characterize a reducing decomposition. In fact, the latter has been more generally spoken of as putrefaction.

DECOMPOSITION OF SEWAGE

At its point of origin, as it passes to the street sewer through the house connections, all ordinary sewage may be spoken of as the spent water supply, with its dissolved oxygen and other con-

stituents, plus the impurities removed from water closets, wash basins, sinks, etc. In the sewage there are a wide variety of bacteria, including those coming from the intestinal tract and having no difficulty in living in the absence of oxygen.

The usual decomposition of sewage is believed to be well shown by an experiment described by the author in the 1894 Report of the Massachusetts State Board of Health, page 461. A bottle of fresh sewage was collected from the Lawrence street sewer, one of the principal sewers of the city of Lawrence. It was brought promptly to the laboratory of the Lawrence Experiment Station and analyses were made at once and again at frequent intervals, allowing natural decomposition processes to take place at room temperature. From the results in Table 24 of analyses of the first sample at 10:30 a. m., on March 11, it is seen that the sewage contained a substantial amount of dissolved oxygen and also small quantities of nitrites and nitrates. Until the latter part of the afternoon of the first day it is seen from the analyses that under the given temperature conditions there were no very marked changes until 6 p. m., when the amount of dissolved oxygen was reduced to about one-half of that originally present. On the following morning, however, it was noted that all the dissolved oxygen was absent and that during that forenoon what little was left of nitrites and nitrates also disappeared.

The carbonaceous organic matter presumably acted as the principal source of food supply for the bacteria which increased rapidly during the first few days. No tests were made for carbon dioxide, but there is every reason to believe that there was an increase in this compound in proportion to the oxygen available for aerobic decomposition. The measure of oxidation was taken as the free ammonia which resulted from the breaking up of the organic compounds. Presumably there was a substantially proportional release of nitrogen as free ammonia and of the carbon as carbon dioxide. The hydrogen perhaps was partly oxidized to water and partly set free by cleavage as free ammonia.

No noticeably objectionable quantities of sulphureted hydrogen were produced, although these samples turned black promptly after the exhaustion of oxygen, indicating that sulphureted hydrogen seems to split apart from the decomposed organic compounds and asserts itself to a greater or less extent, depending upon its oxidation or combination with other substances present in the sewage.

TABLE 24.—CHANGES IN COMPOSITION OCCURRING IN FRESH LAWRENCE SEWAGE UPON STANDING IN A BOTTLE IN THE LABORATORY (Parts per Million)

Date of examination		Nitrogen as									Oxygen consumed		Per cent. of saturation of dissolved oxygen	Bacteria per cubic centimeter
		Free ammonia	Albuminoid ammonia			Organic (by Kjeldahl)			Nitrites and nitrates	Total nitrogen				
Day	Hour		Dissolved	Suspended	Total	Dissolved	Suspended	Total			Two minutes	Five minutes		
March 11..	10:30 a. m.	18.5	5.8	2.1	7.9	31.4	9.1	40.5	3.5	62.2	85.0	132.0	57	1,190,000
" 11..	12:30 p. m.	20.6	5.8	2.4	8.2	28.9	11.4	40.3	3.1	63.9	81.0	142.0	60	1,085,000
" 11..	3:00 p. m.	21.0	5.8	2.5	8.3	28.9	10.7	39.6	2.9	63.4	85.0	136.0	60	1,505,000
" 11..	6:00 p. m.	23.4	5.6	2.7	8.3	27.8	9.9	37.7	2.5	63.6	85.0	133.0	30	1,530,000
" 12..	8:00 a. m.	40.7	4.9	3.9	8.8	11.6	12.2	23.8	0.3	64.6	74.0	107.0	0	20,475,000
" 12..	12:00 m.	41.2	4.9	4.4	9.3	11.6	8.2	19.8	0.2	61.0	69.0	98.0	0	23,100,000
" 12..	5:00 p. m.	41.2	4.2	4.2	8.4	11.6	10.1	21.7	0.0	62.7	69.0	98.0	.0	20,000,000
" 13.	10:30 a. m.	42.0	4.7	3.5	8.2	11.6	8.2	19.8	0.0	61.6	60.0	89.0	0	12,810,000
" 14..	10:30 a. m.	41.2	3.3	4.5	7.8	9.4	8.4	17.8	0.0	58.8	55.0	72.0	0	11,235,000
" 15..	10:30 a. m.	41.2	3.4	4.3	7.7	9.3	8.3	17.6	0.0	57.6	49.0	68.0	0	6,825.000
" 16..	10:30 a. m.	41.2	3.5	4.1	7.6	7.5	8.9	16.4	0.0	57.4	48.0	72.0	0	4,485.000
" 18..	10:30 a. m.	42.0	3.0	3.8	6.8	7.4	6.9	14.3	0.0	56.1	51.0	70.0	0	3,420,000
" 19..	10:30 a. m.	42.8	3.0	3.9	6.9	5.9	7.8	13.7	0.0	56.3	50.0	71.0	0	2,341,000

In this experiment it will be seen that after the dissolved oxygen and oxygen from the nitrates were exhausted, there was no increase but a steady decrease of the bacteria in the sewage as determined by the ordinary methods of analyses. Bacterial growths generally ceased, but those of an anaerobic nature began to assert themselves and no doubt grew prolifically even if not recorded by the ordinary methods of analyses. They produced various decomposition products which unfortunately were not tested for, but a description of which will be found later in general terms. In fact, the diagnosis of the nature of some of them is quite simple from the quotations made above from the important writings of Profs. Nichols and Drown.

Another feature in connection with this test is the variable and irregular results obtained as to the amount of organic matter in the sewage as shown by the tests for albuminoid ammonia, organic nitrogen by the Kjeldahl method, and oxygen consumed. They throw much light upon the crude methods now available to measure in precise terms the organic matter in sewage.

Another feature which is rather significant in Table 24, is the fact that after the aerobic decomposition ceased, following the exhaustion of all available oxygen, then as the total organic matter decreased in amount, the diminution occurred chiefly in the dissolved and not in the suspended matter. This will be touched upon later, but here mention is made of this subject to record the belief that when aerobic decomposition ceases it by no means follows that anaerobic decomposition of the suspended organic matter takes place at once, as claimed by some concerning the so-called septic process.

At Gloversville, N. Y., a similar test to the one above described was made. Corresponding results were obtained as shown by the results of analyses, in parts per million, stated on page 67 of the 1909 report of Messrs. Eddy and Vrooman, as given in Table 25.

FRESH, STALE AND SEPTIC SEWAGE

Considerable difference is found in the quality of various sewages, according to the size of the sewerage system and particularly the time interval which elapses for the flow of sewage from its point of origin to the outfall or disposal works. This has been stated so clearly by Mr. H. W. Clark, on pages 434–5 of

TABLE 25.—CHEMICAL RESULTS SHOWING EFFECT OF INCUBATING A SAMPLE OF GLOVERSVILLE, N. Y., SEWAGE AT ROOM TEMPERATURE FOR 7 DAYS WITH ANALYSES EVERY 24 HOURS

Number of hours incubated	Nitrogen as						Oxygen consumed			Alkalinity	Suspended matter			Residue on evaporation								
														Total			Volatile			Fixed		
	Total organic	Dissolved	Suspended	Free ammonia	Nitrites	Nitrates	Total	Dissolved	Suspended		Total	Volatile	Fixed	Total	Dissolved	Suspended	Total	Dissolved	Suspended	Total	Dissolved	Suspended
Initial	29	15.0	14.0	11	0.16	1.20	107	59	48	240	328	208	120	1255	944	311	247	129	118	1008	815	193
24	22	11.0	11.0	15	0.04	0.11	99	47	52	240	406	266	140	1213	903	310	255	106	149	958	797	161
48	18	6.3	11.7	19	0.00	0.00	90	38	52	240	308	206	102	1157	879	278	227	75	152	930	804	126
72	14	4.3	9.7	25	0.00	0.00	86	44	42	240	356	230	126	1173	887	286	280	100	180	893	787	106
96	14	4.3	9.7	25	0.00	0.00	93	34	59	270	354	222	132	1122	856	266	206	45	161	916	811	105
120	15	4.1	10.9	24	0.00	0.00	85	30	55	290	286	182	104	1131	860	271	155	49	106	976	811	165
144	13	.....	.....	24	0.00	0.00	77	27	55	290	282	186	96	.....	.....	.....	.....	.....	.....	.....	.....	.....

the 1898 Report of the Massachusetts State Board of Health, that his language is given in full, as follows:

Sewage is the filth flowing in our sewers, consisting of wastes from houses, stores and streets, together with the water used for washing these wastes into the sewers. In many places, waste liquors from industrial establishments largely augment the volume of sewage.

It is evident that, when this mixture of filth and organic matters of all kinds, with the waste water of a town, has just occurred, and little time has been given for mechanical, chemical and bacterial actions to take place in the sewers, we have a liquid containing organic matter quite differently constituted—that is, of a different mechanical and chemical composition—from the same matter in the sewage when opportunity has been given for these various actions to take place. The sewage at first contains generally free oxygen and nitrogen in the form of nitrates and nitrites, and the proportion of organic matters in suspension is comparatively large. Such a liquid we call *fresh sewage*

As this fresh sewage flows along the sewers, mechanical, chemical and bacterial forces act upon it, and the composition of its organic constituents undergoes a distinct change. This change is practically the breaking up of the organic matter into simpler forms, and is the initial step in the process by which the organic matter is finally changed to inorganic matter. The change carried on in fresh sewage containing free oxygen is as follows: The carbon, under bacterial influences in the presence of free oxygen, is oxidized, the nitrogen and hydrogen unite to form ammonia, and this unites with the carbon dioxide to form ammonium carbonate. Thus, until the dissolved oxygen is exhausted, the free ammonia increases, while the crude organic matter decreases. Sewage when its free oxygen has just become exhausted and its free ammonia increased to the maximum possible by the exhaustion of its oxygen we designate as *stale sewage.*

Sewage containing free oxygen and for this reason comparatively free from putrefying actions has not a particularly offensive odor, and the same can be said, though in a less degree, of stale sewage. When the oxygen is exhausted, bacterial life continues active and chemical changes go on and continue the breaking up of the organic matter into simpler forms. But, as oxygen is not present, the action by which the organic matter is still further changed is a putrefying one, and the sewage becomes very ill-smelling on account of the generation and escape of hydrogen compounds of carbon, sulphur and phosphorous. Nitrogen is also set free in this putrefying process. The result of all these changes is to decrease the amount of carbonaceous and nitrogenous matter in the sewage. Sewage when in this state is now known, since the results of certain English experiments have been published, as *septic sewage;* not a very appropriate term, but one which we shall probably have to

accept on account of its general use at the present time. This action, resulting in the change of stale sewage into septic sewage, can probably, if sufficient time is given, be continued until nearly all the organic matter in suspension is changed into soluble forms.

In tables 24 and 25 it is shown that whether sewage is fresh or stale it is the soluble and not the suspended organic matter which is decomposed. Many days seem to be required by anaerobic bacteria in the substantial absence of oxygen before there are established enzymes or other conditions of anaerobiosis which attack the suspended organic matters.

Importance of the Subject.—Attention is given to this feature in order to emphasize the fact that it is not necessary to have septic sewage in order to produce in sewers a dark colored liquid which smells badly. In other words, anaerobic decomposition and septicization ought not to be used interchangeably. The former but not the latter begins when aerobic decomposition ceases.

When sewage contains bacteria or their products which, in the absence of oxygen and either directly through cell activities or indirectly through enzymes, liquefy, and gasify the suspended organic matter, we say that septicization is taking place. This definition is crude. It is suggested in order to emphasize the importance of time and other factors which have to be taken into account in considering the septic process. It also serves to show the importance of conveying sewage to its point of discharge with a minimum opportunity for stranded solids within a sewer to become septicized so that enzymes may diffuse through and affect the flowing sewage.

NITRIFICATION AND DENITRIFICATION

In the course of oxidation and reduction changes, comprising aerobic and anaerobic decompositions, the nitrogen passes through a well-known cycle. It is only partly illustrated, however, by the analytical data of tables 24 and 25. As soon as the organic matter begins to decay in the presence of oxygen, it gives up more or less free ammonia as a decomposition product. This intermediate step arises from the splitting apart of the original molecule, and the releasing of ammonia, which ordinarily combines with carbon dioxide to form ammonium carbonate as stated by Mr. Clark. It is this ammonium carbonate which, upon distillation in the laboratory, yields the free ammonia recorded

in analytical data. This intermediate nitrogen product is a stable one, comparatively speaking. It was a long time before it was finally understood how it was converted to a completely oxidized and mineralized state.

About twenty years ago the careful work of Winogradsky, Frankland, Jordan, Richards and others showed that there were special species of bacteria, not requiring much if any organic food for their growth, which converted the nitrogen into nitrates. One or more species seem to be involved in this step, and frequently if not always there is a second intermediate step known as the nitrite formation. It is these nitrifying bacteria which, in the presence of oxygen, establish themselves upon the surfaces of filtering material and effect the nitrification which is so conspicuous in intermittent sand filters. The main point which it is here desired to establish is that nitrogen coming from organic matter may be converted into the completely oxidized nitrogen as nitrates; and this in turn, serving as food for grosser living organisms, may be converted into organic matter to die and pass through the cycle again in never-ending series.

While the oxidizing or aerobic decomposition of organic matter produces nitrates, it is not true, however, that all of the nitrates serve as a food for larger forms of life and thus are changed to organic matter directly. In fact the nitrates, when found under conditions of anaerobic decomposition, are themselves reduced through the withdrawal of oxygen by the bacteria. This step is known as denitrification and it forms quite a conspicuous feature in some of the bacterial processes of sewage purification. Different species of bacteria reduce nitrates differently. Some reduce it to nitrites, others to free ammonia, and others to nitrogen gas which escapes into the atmosphere.

In short, it is seen that nitrogen as nitrates passes through a more or less reversible cycle according to whether the product is acted upon under aerobic or anaerobic conditions.

REDUCTION OF MINERAL SULPHATES; DESULPHURIZATION

Denitrification is not the only characteristic feature in the anaerobic decomposition of sewage with respect to changes in mineral contents. While there are comparatively many bacteria which are able to obtain oxygen from nitrates before they pass from an aerobic to an anaerobic basis, there are some species of

bacteria that are able to withdraw oxygen from the ordinary sulphates dissolved in water supplies and sewage, such as the sulphates of the alkalies and alkaline earths.

When mineral sulphates are reduced, the sulphur is ordinarily changed to a sulphide or sulphureted hydrogen. This malodorous substance makes this reduction highly objectionable from the standpoint of nuisance-producing odors. There are also quite a number of instances on record where sulphureted hydrogen has been produced in quantities sufficient to overtax the flowing sewage with respect to its capacity for converting the sulphur into sulphide. Then the sulphureted hydrogen reaches the surface of the flowing liquid and escapes as a gas above the flow line in the sewer or other carrier. Where oxygen of the atmosphere freely meets this sulphureted hydrogen, sulphuric acid is produced. It seriously affects the integrity of structures where the acid accumulates in drops or otherwise above the flow line. Below the water surface the acid becomes diluted and combined with other substances so as to prevent solvent actions.

The first time that the author had opportunity personally to appreciate the significance of this reduction was in connection with the tests made of various settling basins investigated for the new water purification project for Cincinnati, Ohio, in 1898. On page 119 of his report describing those tests, reference is made to the sediment layer of sludge deposited upon the bottom of the tanks used for the preliminary clarification of the muddy Ohio river water. The tanks were used on the fill-and-draw plan, each tank being about 25 feet in diameter and 34 feet deep. On the bottom of these tanks sediment was deposited as a layer whose consistency gradually increased, partly due to the compacting of the layer and partly to the decomposition processes.

After the oxygen was exhausted in the water within the sediment layer, the bacteria made every effort to secure oxygen from nitrates, sulphates and no doubt from the ferric oxide of the silt. There also appeared certain bacteria which it is believed liberated considerable amounts of hydrogen sulphide, coming apparently to a considerable extent from the reduction of sulphate of lime and magnesia.

The next step seemed to be a reaction between the sulphide compounds and the ferrous iron, resulting in the formation of ferrous sulphide. This is a black gelatinous precipitate, which formed the cementing material for converting the thick fluid in

a month or two into a semi-solid mass of a tenacious character more or less resembling rubber.

This observation was not confined to the testing station at Cincinnati, but it was also noted at certain inlets to the pump wells at the old Front street pumping station near the Pennsylvania railroad station. It would naturally be expected that sulphureted hydrogen coming from the decomposition of organic matter would account for considerable ferrous sulphide. But in the instances cited the amount was so surprisingly great that it is believed it could be reasonably accounted for only by the presence of certain species of bacteria which caused the reduction of mineral sulphates.

At the Columbus, Ohio, sewage testing station this matter was carefully watched in 1905 on account of the large amount of mineral sulphates present in the local sewage. It was found, however, that during the tests there were no signs of the mineral sulphates being decomposed in the tanks and filters and that whatever sulphureted hydrogen was then formed came from the breaking down of organic matter. (See page 123 of the "Report on Sewage Purification," Columbus, Ohio, 1905, by Mr. George A. Johnson.) On page 144 of his report, Mr. Johnson speaks, however, of odors about a coke strainer, as follows:

> *Odor.*—At all times during their operation there was a pronounced odor of sulphureted hydrogen about the discharge pipes in the coke strainers. The cause of this was presumably due to the intimate contact under highly anaerobic conditions of the sludge in the coke layer and the applied sewage, causing a formation of the gas from the decomposition of the organic matter present, and perhaps from the partial reduction of the sulphur in the coke and the sulphates in the applied sewage. The hydrogen sulphide thus formed was in such relatively large amounts that the iron in the sewage and the sludge was insufficient to hold the gas as iron sulphide, as was probably the case in the septic tanks.

At the main sewage purification works at Columbus it is understood that there has been some evidence as to sulphate reduction.

At Lawrence, Mass., as stated by Mr. H. W. Clark on page 251 of the 1903 Report of the Massachussetts State Board of Health, experiments on septic tanks were made with local sewage to which mineral sulphates were added, and there was obtained a substantial reduction of the sulphates with a corresponding increase in

sulphureted hydrogen over that in septic tanks operated with the normal sewage.

Similar reductions in mineral sulphates were indicated by the work of Profs. Winslow and Phelps at the Institute of Technology in Boston, where the sewage contained mineral sulphates due to the entrance of sea water at the outfall sewer. Sulphate reduction was also reported from Worcester, Mass., where the sewage contains much waste sulphuric acid from steel works.

The reduction of sulphates is found at Chicago in a "biolytic" tank, in which all the incoming sewage passes through the entire sludge. The action is marked even in a nominal period of 6 hours' flow.

INJURIES TO MASONRY

The most striking occurrence of sulphureted hydrogen in large quantities at sewage purification works, as noted by the author, was at the plant at Nuneaton, England. The concrete carriers were seriously affected and it became necessary to put on wooden covers and make every effort possible to prevent the entrance of air into them. The purpose of this was to prevent oxygen from oxidizing the sulphureted hydrogen into sulphuric acid which was the cause of the disintegration of the concrete and metal structures. This plant, at the time of the author's visit, was treating the sewage from a community of about 30,000 people which derived its water supply from the vicinity of the coal measures and from which water it was necessary to remove iron before delivery to the water consumers.

In this country, particularly on the Pacific coast, there are a number of instances where the integrity of concrete, metal and mortar, both in outfall sewers and septic tanks, has been affected through bacterial agencies bringing about the production of unusual amounts of sulphureted hydrogen. Perhaps the most striking case was at the outfall sewer of Los Angeles, Cal., where the mortar and even the brick showed signs of disintegration after a short period of use. The affected parts were above the flow line, where the sulphureted hydrogen became oxidized by the atmosphere to sulphuric acid.

No such disintegration occurred in siphons where the sewer was constantly filled with liquid. The water supply of that neighborhood is quite highly mineralized and there seemed to be something in the character of the mineral contents of the sewage that pro-

moted the development of those kinds of bacteria that reduce sulphates of the alkalies and alkaline earths to sulphureted hydrogen. The difficulty was obviated to a substantial degree by damming up the sewage so as to exclude air from the affected parts. An instructive report on the subject by Mr. Homer Hamlin, City Engineer of Los Angeles, is to be found in *Engineering News* of Nov. 8, 1900.

Signs of disintegration of masonry are to be noted near the outlet of numerous septic tanks, due to acid formed by the oxidation of sulphureted hydrogen. Such action may result from the sulphur in the organic matter of the sewage. But the most aggravated cases seem to come from the reduction of mineral sulphates. Why the latter are reduced at some places and not at others seems to be a question of voluntary "seeding" or establishment of the needed types of bacteria.

Lafar in his book on "Technical Mycology" (English Translation of 1898, Vol. I, page 293), makes the following interesting comment:

> The conversion of sulphates into sulphides by bacterial agency is also a decisive indication of reducing power. The conditions of vitality of a particularly active species of fission fungus were investigated by Beyerinck, who named the organism *Spirillum desulfuricans.* This strictly anaerobic microbe is utilized in practice in so far that by skillfully encouraging its development, pit-water very rich in gypsum has been entirely freed from sulphates ($CaSO_4$ being converted into CaS and FeS), and rendered suitable for various purposes, such as feed-water for steam boilers, etc.

In a recent paper before the Iowa Association of Cement Users, reference is made to bacteriological studies by Prof. R. E. Buchanan of the Iowa State College. Excessive production of hydrogen sulphide with disintegration of concrete above the water line in dosing chambers for septic effluent was present in two and absent in seven installations. High content in mineral sulphates (1645 and 476 parts of SO_4 per million) in the water supply seemed to distinguish the former from the latter group of installations, all built along similar lines. Prof. Buchanan isolated normal sewage bacteria which have the power to reduce mineral sulphates with the liberation of hydrogen sulphide. He also isolated from the sulphur deposits on the walls where disintegration had occurred certain types of bacteria which had

sulphur granules within their bodies and were converting hydrogen sulphide and sulphur to sulphuric acid.

Mr. Rudolph Hering contributed important experiences on this subject in the *Transactions of the American Society of Civil Engineers*, Vol. LXVII, page 594. Some additional references to this subject are the following: *Engineering Record*, May 14 and 28 and July 2 and 30, 1910; *Engineering News*, June 2, 1910; *The Surveyor* (Supplement), April 29 and May 6, 1910; also *Municipal Engineering;* July, August, September, and October, 1909; March, July, and November, 1910.

RELATION OF BACTERIA TO DIFFERENT COMPOUNDS OF SULPHUR

Bacterial action is related to sulphur compounds in three ways. One bacterial function is to produce sulphureted hydrogen from complex organic matter in sewage; a second is the desulphurization of dissolved mineral sulphates coming from the water supply; and a third, accomplished by the true sulphur bacteria, is the utilization of sulphureted hydrogen for their own growth, with the resulting conversion of this product to metallic sulphur, sulphuric acid, and eventually to mineral sulphates.

The complex proteid substances in sewage, with thousands of atoms in their molecular composition, seem to contain sulphur in a form that is easily removed. Opinion differs with respect to the manner of removal of sulphur, although Jordan, Lafar and others state clearly that sulphureted hydrogen is produced from protein bodies by most of the common laboratory forms of bacteria. Lafar also states that this faculty is very common among the pathogenic bacteria and was absent in not a single one of 37 species examined.

It appears that it may be formed by cleavage or a splitting off of H_2S groups already present in the molecule. It also may be formed, according to Petri and Marsson, by nascent hydrogen, liberated by the bacteria, which extracts sulphur from a compound and combines with it. Prof. Boyce in the Second Report of the Royal Commission on Sewage Disposal of Great Britain, page 107, states that Hoppe-Seyler found that H_2S may be formed from the reduction of calcium sulphate by marsh gas in a nascent state.

Different species of bacteria, acting upon different kinds of organic matter, may proceed in different ways, but practically

speaking, it is sufficient to note that sulphureted hydrogen is easily produced from a variety of albuminoid substances by a great many and probably most of the ordinary kinds of bacteria found in sewage.

The aggravated cases of production of sulphureted hydrogen appear to be caused by the desulphurization of mineral sulphates. Whether or not this is due to a single organism, *Spirillum desulfuricans*, as mentioned in the quotation from Lafar above, we do not know. Neither are we informed as to whether such bacteria are present in all sewages but precluded by antagonism from performing conspicuously this function until the sulphates are present in such quantities as cause antagonism to aid and not hinder it. Possibly symbiosis is of importance. It would be helpful to have further information along the lines of the recent studies of Prof. Buchanan of Iowa. Included in such studies should be the most ready means both of preventing and offsetting the results of this reduction process.

The true sulphur bacteria have a directly opposite physiological effect from that of the reducing bacteria just mentioned. They do not produce sulphureted hydrogen, but form sulphuric acid, which, combining with the mineral carbonates in water or sewage, form a sulphate of the alkalies or alkaline earth metals.

Two genera of the true sulphur bacteria are recognized, *Beggiatoa* and *Thiothrix*. The former is motile, filamentous and morphologically resembles the alga *Oscillaria*. *Thiothrix* is not motile nor filamentous, and it possesses a sheath and forms spores. Some of the sulphur bacteria are red or purple. They have been studied carefully by many biologists. Their physiology has been well stated by Jordan in his book on "General Bacteriology," page 96, as follows:

> The physiology of the group of sulphur bacteria is unlike that of any other living organisms, and they deserve to be set apart, as Winogradsky has proposed, as an independent physiologic group. The true sulphur bacteria all contain in their protoplasm highly refractive inclusions which have been found to be amorphous sulphur. The presence of sulphur in the cell is undoubtedly connected with the fact that the organisms are only found abundantly in waters containing sulphureted hydrogen. The discovery of the full physiologic significance of these findings has been largely the work of Winogradsky. By the oxidation of sulphureted hydrogen to sulphuric acid, which is, of course, at once neutralized by the carbonates present, the sulphur bacteria obtain the energy necessary

for their development. Sulphureted hydrogen, in a word, is their principal food. According to Winogradsky, the single Beggiatoa threads use in a day two to four times their own weight of H_2S. The sulphur in the cell-protoplasm is to be looked upon as an intermediate stage in the oxidation process. The course of the reaction may be indicated by the following equations:

$$(1)\ 2H_2S+O_2=2H_2O+S_2.$$
$$(2)\ S_2+3O_2+2H_2O=2H_2SO_4.$$

That sulphureted hydrogen is indispensable for the continued activity of these organisms and is for them the sole available source of energy is inferred from the fact that if it is not accessible, the store of sulphur in the cells quickly disappears (in 24 to 48 hours) and the bacteria apparently then die from starvation. It seems probable that the sulphur bacteria require no organic substances for their development, but that, like the nitrite bacteria, they can subsist on a purely mineral diet. For these organisms, therefore, sulphur in its combination with hydrogen seems to have the same physiologic value that carbon in its hydrogen compounds has for most other bacteria.

Their life history is well summed up by Lafar on page 372 of his book above mentioned, as follows:

The existence of the sulphur bacteria is often a very hard one, because it requires the simultaneous presence and availability of two gases which neutralize one another and become converted into sulphur and water . . . .

$$H_2S+O=H_2O+S$$

So that actually the surface of liquids, wherein H_2S is produced in abundance by the activity of reducing bacteria, becomes coated with sulphur formed by purely chemical means, in accordance with the foregoing equation. Now, in order that the sulphur bacteria may be in a position to exert their powers of oxidation, it becomes necessary for them to inhabit certain strata of the liquid between the limits where the oxygen can gain access from above and sulphureted hydrogen reach them from below. If the liberation of the latter gas goes on briskly, this level rises and may ascend to the surface of the liquid; otherwise it sinks and approaches the bottom, where the sulphureted hydrogen is generated. This change of feeding-ground cannot, however, be followed by all species of sulphur bacteria, since—just in the same way as has been explained with regard to sulphureted hydrogen—these organisms are adapted to a certain tension of oxygen, which varies in the different species, *i.e.*, they cannot stand the presence of more than a certain quantity per unit of volume of the liquid. In the case of oxygen this tension is naturally greatest at the surface and smaller at greater depths.

It will be evident that even the fluctuations of atmospheric pressure will suffice to produce a change in the predominating species of a diversified mixture of sulphur bacteria in their natural haunts. The same applies to the rate at which the sulphureted hydrogen is disengaged.

The importance of the sulphur bacteria in the economy of nature is unmistakable; in cooperation with the sulphate-reducing bacteria they insure that the sulphur cycle pursues an uninterrupted course, the element being taken up by the higher plants in the condition of sulphates, and deposited in the cells in the form of organic compounds, from which, in the course of putrefaction, it is liberated as sulphureted hydrogen, and is finally then reconverted into sulphates by the sulphur bacteria and recommences its course through the higher plants.

RESIDUAL RESULTS OF DECOMPOSITION

A clearer conception may perhaps be obtained as to what is meant by decomposition of sewage if we refer briefly to the end results obtained. These may be grouped under several headings, such as mineralization, humification, and intermediate decomposition products. Comments will be made briefly upon them as follows:

Mineralization.—In Nature's economy decomposing organic matter is converted to mineral matter to serve as food for higher forms of life, as has been brilliantly summarized by the pupils of Pasteur and as quoted at the beginning of this chapter. In the field of sewage disposal mineralization takes place to some extent regardless of attempted control of the method. It is capable, as in intermittent sand filters, of being carried to a relatively high degree of completeness.

It is not so important, however, to see to the completeness of mineralization as it is to ascertain the quality and quantity of the remaining organic matter. From what has been said already it is plain that nitrogen is converted to nitrates, sulphur to sulphates, hydrogen to water, and carbon to carbonic acid or carbonates. We have not attempted to look fully into the history of phosphorous, but it is probable that all of the elements or atoms of the extremely complex molecules of organic matter found in sewage are capable of conversion into completely mineralized form. Prof. Marshall speaks of the phosphorus cycle, and a description of the formation of phosphine is given in the *Centralblatt für Bakteriologie*, Dec. 16, 1911.

Humification.—Organic matter is humified when it has been acted upon bacterially so that it will decompose or rot no more. The expression is derived, of course, from the humus found in nature. It is perhaps best illustrated by the relatively stable products resulting from decomposition of leaves, as found in the forest after the removal of the carpet of undecomposed or decomposing leaves. All of these expressions are to be considered in a relative sense. It is probable that in time, as measured by centuries, all such organic matter may be completely mineralized. The persons in charge of sewage disposal works, however, need not bother themselves about the final steps of this process, as they have enough to consider in the most economical means of dealing with sewage when in a state where it is still rotting or capable of rotting.

This brings up the question of the oxygen balance and the relation between the available oxygen and the oxygen-consuming power of the organic matter. It deals with the aerobic as distinguished from the anaerobic basis of decomposition with the offensive products of the latter. This has led in recent years to the development of the incubation and putrescibility tests, and on more precise lines to the development of stability tests, as detailed by Prof. Phelps. The needed degree of stability varies somewhat under different conditions and with the views of different persons. For instance, Dr. Dunbar of Hamburg has indicated that filter effluents are reasonably stable when purified to the extent of releasing all organic sulphur.

Whatever the outcome may be ultimately, it is the opinion of the author that future progress will be more rapid and satisfactory if more attention is ordinarily given to stability studies and less to the old-fashioned determinations of albuminoid ammonia, Kjeldahl nitrogen, etc.

Decomposition Products.—In all sewages there is an unstable portion of the organic matter as distinguished from the stable portion. The unstable portion breaks up into various products some of which have offensive odors and others not. As a general proposition it will be best if sewage is disposed of so as to keep the intermediate products of decomposition, so far as possible, on an aerobic and not on an anaerobic basis.

Putrefaction in its true technical meaning, and perhaps anaerobically, may be at work within the particles of organic matter in fresh sewage. But objectionable results do not show

themselves conspicuously if these particles are surrounded with oxygen-containing water. For this reason, among others, sewage should be disposed of in as fresh condition as practicable. Where such sewage disposal is not practicable, it is necessary to proceed with as efficient control as may be of the products of decomposition. With that in view we will speak briefly of some of the characteristics of these products.

CHARACTERISTICS OF DECOMPOSITION PRODUCTS

Even with our knowledge of the nitrogen and sulphur cycles, available information as to the biochemistry of sewage decomposition is meager. Perusal of the literature shows fair agreement on a number of points, but there is a lack of definite information upon the way in which the products are made. This is well outlined in the paper of Dr. Kendall, quoted above, representing three years' work.

There is little room for doubt as to fermentation taking general precedence over putrefaction. This seems true regardless of the presence or absence of oxygen. If in a mixture containing both carbonaceous and nitrogenous products there are bacteria which are able both to ferment and to putrefy the mixture, they will start with fermentation of the products resembling carbohydrates, rather than with putrefaction of the proteid matter.

Free oxygen, within the zone of its influence, promotes aerobic rather than anaerobic decomposition in the presence of facultative bacteria capable of growing either in the presence or absence of oxygen.

Another point upon which there is substantial agreement is that obligative anaerobes seem to institute the beginnings of putrefaction, and that the facultative anaerobes carry the albumoses, peptones, fatty acids, aromatic acids, etc., to the simpler forms ordinarily spoken of as decomposition products. Dr. Kendall outlines this point clearly, and it is in line with other writings. In this connection it is to be borne in mind that for sewage work comparatively little is known of the obligate anaerobes. They can be cultivated only in an atmosphere free of oxygen. Perhaps the time interval is of vital importance in explaining some features of sewage disposal, where products appear in fairly simple form only after an opportunity for various bacteria to work in symbiotic relation.

From a chemical standpoint available information seems disappointing in that we do not know very much about the manner of production of the simpler decomposition products. We do not know how far these products as such split apart from molecules of original or intermediate compounds or whether decomposition deals with atomic conditions and subsequent combinations of the individual atoms.

Leading literature on the subject has been perused repeatedly by the author with a growing feeling that the problem is complex and much in need of further elucidation. Perhaps the principal point that has occurred to him is that in sewage decomposition many different combinations may take place at the same time in different parts of the same portion of sewage. Thus, within different particles of feces, the intestinal bacteria may be proceeding upon an anaerobic basis, either fermentative or putrefactive, depending upon the content of the intestinal tract from which the feces originated. At the same time on the exterior of such particles another set of bacteria may be at work on an aerobic basis. Combinations between the products of decomposition, and the oxygen and other constituents of the water with which the intestinal discharges are mixed, may disguise and eliminate the ready detection of what the fundamental actions really are.

This subject will be dismissed with a recital of some notes as to the nature of the decomposition products which may be of assistance in considering some aspects of sewage disposal problems.

Carbon Dioxide.—This is the characteristic end product of aerobic fermentation. It is formed, however, in an anaerobic decomposition, as shown by its appearance in the gases from septic tanks. Under some conditions it evidently is released by cleavage. It is formed in sewage or sewage-polluted waters in a number of other ways. It may be absorbed from the atmosphere, liberated by plant and animal life through the process of respiration, and under some conditions it may be obtained from the dissolved carbonates. Chlorophyl-bearing organisms consume it in proportion to the oxygen produced. It is a gas fairly soluble in water.

Carbon Monoxide.—This gaseous product has been reported as being found in the gases from septic tanks. It does not seem to be conspicuous as an anaerobic decomposition product.

Methane.—Marsh gas, or methane, is the principal carbonaceous compound resulting from anaerobic decomposition. It is

normally the most voluminous gas coming from septic action. It is not confined to sewage decomposition, but is the conspicuous compound resulting from the decomposition of the sediment in mill ponds and from the vegetation which is acted upon to produce natural gas. It is sparingly soluble in water.

Indol.—This is a decomposition product of albuminous bodies and has a peculiarly putrid odor. It is formed by many bacteria, and is used in the laboratory as a diagnostic test. It does not appear as a gas, but through volatilization or evaporation it makes its presence felt. It is allied more or less to skatol, cadaverin, and putrescin. This group of products seems to appear as a result of facultative anaerobes acting on certain products which may also give off ammonia and carbon oxide.

Ammonia.—This product is most characteristic of the decomposition of urea. When present in sufficient quantities it gives a characteristic odor, such as noticed around stables, barnyards, urinals and ferryboats. It is very soluble in water.

Nitrogen.—This gas is found in the products of anaerobic decomposition. In part it may come from the reduction of nitrates and allied compounds, and in part it may come by direct release from complex molecules.

Hydrogen.—This gas, like nitrogen, seems to be released in an anaerobic decomposition. It results from fermentation and probably also from putrefaction.

Sulphur Compounds.—Sulphureted hydrogen has already been spoken of as a gas released in the decomposition of sulphur-containing organic compounds and from the reduction of sulphates. Mercaptan is another sulphur compound representing one of the further products of decomposition. It does not exist in the gaseous form, but like indol, skatol, etc., it produces by evaporation and volatilization an intensely foul odor.

Phosphine.—Phosphorus compounds under some conditions are converted to this gas (PH_3), according to Marshall's "Microbiology," page 116. It has a strong disagreeable garlic odor and is only very slightly soluble in water.

RÉSUMÉ

Sewage contains a complex mixture of organic substances and numerous kinds of bacteria. Practically all organic matter in water decomposes in the presence of bacteria. The rate and manner of decomposition varies much, depending upon numerous factors.

So long as dissolved atmospheric oxygen is available aerobic decomposition takes place. When oxygen, dissolved in the water as a gas or available from certain compounds, is exhausted, then bacterial decomposition proceeds upon an anaerobic basis.

So long as available oxygen is present the sewage is fresh. When anaerobic decomposition begins it is stale. For a time it is the soluble organic matter that is then decomposed through the protoplasmic activities of the bacterial cells. Sooner or later enzymes are excreted by the anaerobic bacteria and these soluble products proceed to liquefy and gasify suspended organic matters. This is spoken of as the septicization of sewage.

The various atoms of the complex organic molecules seem to pass through cycles in which the bacteria play a powerful and important part as agents of universal hygiene.

Some of the products of decomposition are of a simple character, well known in nature. Part of them are odoriferous and others are not. If we subtract from the original organic constituents of sewage the sum of all of the well-known simple decomposition products and also the residual humified matter, there are still left numerous intermediate compounds which are dissolved in sewage and about which data are limited.

Hitherto fermentation and putrefaction have been used loosely, and interchangeably with aerobic and anaerobic decomposition, respectively. A better working knowledge can be obtained, if the definitions of these processes in this chapter are adhered to more closely, with respect to deoxygenation of the water composing sewage and with regard to polluted water as well as septicization and various processes of purification.

This subject of decomposition is important, as it is intimately associated with the efficiency and economy of disposal projects. Especially does it relate to the question of nuisance from the disposal works themselves and even the integrity of structures used for sewers and sewage disposal works.

CHAPTER III

SEWAGE BACTERIA AS RELATED TO OFFENSIVE ODORS

The term "sewage bacteria" is here used in a broad sense, intended to cover the results not only of the protoplasmic action of vegetative cells, but also of the unorganized ferments or enzymes. Perhaps it would be well from a strictly biological standpoint to include with the bacteria such other microorganisms as are capable of effecting the decomposition of sewage along the lines described in Chapter II.

Bearing in mind that sewage may be decomposed by bacteria until ultimately the organic matter is humified or mineralized, we will here deal with the question of its unstable as distinguished from its stable organic constituents. That is, further discussion will now be given to what the bacteria accomplish with the unstable portions of sewage and to the relation which their transitional and end results have to nuisances, particularly bad smells.

RELATION OF DECOMPOSITION TO NUISANCES

Consideration of practical sewage disposal projects quickly forces attention to the nuisance question. Briefly, the principal nuisances may be classified generally in two groups, as will be detailed subsequently. The first relates to the effect of the bacteria themselves in contaminating waters and shellfish. The second involves the effect of the odoriferous products of decomposition.

Exhaustion of oxygen in waters receiving sewage is an important allied matter, particularly in its relation to fish life, as will be noted under discussions upon the disposal of sewage by dilution in streams and lakes.

The bacteria of sewage are always present in the untreated product and frequently include some germs of disease. Their disposal relates to matters of filtration and sterilization as will later be touched upon at length, after detailing their effect upon the public health in connection with shellfish and polluted water supplies.

In the disposal of sewage in works of modern construction, it is necessary to give special attention to the question of odors. Large quantities of decomposing organic matter naturally suggest some odor, and to keep it within narrowly-confined limits is an undertaking requiring much care both in the design and maintenance of disposal works.

We shall consider in this chapter the bacteria in their capacity to bring about certain changes in sewage, which approach the direction of a nuisance through offensive odors unless the latter are prevented or controlled.

OXIDATION AND REDUCTION OF SEWAGE

Aerobic and anaerobic decomposition of the organic matters of sewage bring about indirectly through biological agencies the oxidation and reduction, respectively, of various sewage compounds. This is not the case with the ordinary chemical agencies as found in sewage disposal works, except to a limited degree under certain restricted conditions.

Atmospheric oxygen will oxidize none or but little of the organic content of fresh sewage. Even most of the unstable organic matter is unaffected by the oxygen of the air. Years ago this was well demonstrated by numerous tests made in different parts of the world to oxidize sewage by prolonged aeration. Perhaps the best proof is to be found in the fact that many hours elapse after sewage leaves its point of origin before it loses the atmospheric oxygen contained in the water which carries away the household wastes. The gradual and time-consuming oxidation of organic matter by bacterial agencies, rather than by direct oxidation by atmospheric oxygen, is again well illustrated in the modern incubation or putrescibility tests which have led recently to more precise methods for the determination of stability.

It is true, however, that some unstable matters in sewage are capable of combining quite readily with atmospheric oxygen. The English custom of determining oxygen consumed after 3- and 15-minute intervals of contact with acid permanganate illustrates the desire to measure the small quantities of fairly unstable organic matter. Some of the decomposition products already mentioned, such as sulphureted hydrogen, probably are capable of combining with oxygen either as dissolved in the water or as found in the atmosphere. Most of the products of

sewage even after it has undergone more or less decomposition may be rated as substantially stable through direct chemical oxidation. The effluent of comparatively large septic tanks upon aeration may show considerable capacity to absorb quickly in chemical combination more or less oxygen of the atmosphere.

Hydrogen is generally considered a good reducing agent and yet it is released in septic tanks in a gaseous form, evidently incapable of effecting material reduction of the highly complex organic compounds in a sewage undergoing active decomposition.

MINIMIZING OF ODORS THROUGH AEROBIC DECOMPOSITION

From the standpoint of preventing objectionable odoriferous products of decomposition, there is no lesson so important to be learned as that the decomposition should, just as far as practicable, be conducted on an aerobic basis.

Sewage at its point of origin, materially influenced in its composition by intestinal discharges, is not entirely lacking in anaerobic decomposition. If fecal particles undergoing anaerobic decomposition within their interior are surrounded with oxygen-containing water, however, it is quite likely that there may be some direct oxidation of some decomposition products such, for instance, as sulphureted hydrogen. Hydrogen and carbon may be so oxidized to water and carbonic acid, respectively.

Aerobic decomposition is preferred by sewage bacteria as a general proposition to anaerobic decomposition. So long as the oxygen dissolved in the water of sewage is able to maintain aerobic conditions, there will be a minimum of complication from anaerobic decompositions. This may perhaps make a little plainer than hitherto the importance of conveying sewage from its point of origin to its point of disposal with a minimum time interval for the exhaustion of oxygen.

PROPER METHODS FOR GUARDING AGAINST ODORS IN SYSTEMS OF COLLECTING SEWERS

For some thirty years beginning with the comprehensive report outlining the scientific principles on which European sewers were built, prepared by Mr. Rudolph Hering at the request of the National Board of Health, it has been known that sewage should be brought to the point of disposal as promptly as possible and with minimum opportunity for decomposition of stranded materials within the pipes. As knowledge has increased with

respect to decomposition of sewage, it has become clearly recognized that additional care should be required in the collection of sewage from the standpoint of guarding against objectionable odors. The principal features requiring attention are as follows:

Ventilation of Sewers.—It is highly important to provide fresh air in the underground channels comprising the collecting pipes of the sewerage system in order to maintain bacterial processes, as far as possible, on an aerobic basis. Lack of ventilation tends to promote in places a needlessly rapid exhaustion of the oxygen dissolved in the water supply as it is discharged into the sewers, and it is not difficult to find some cases where objectionable odors exist in the collecting sewers themselves. In some instances good ventilation will correct this difficulty. In other instances, the fault is a fundamental one in the design of the sewers, and one which ventilation will help, but not cure.

House Connections.—Where plumbing fixtures are provided with suitable traps and with vents leading to a soil pipe that extends above the roof of the building, no good seems to be accomplished by putting a trap on the house connection through which the sewage passes from the building to the street sewer. Connections that are so trapped frequently have their interior coated with a slimy deposit in which more or less decomposition is taking place, whereas similar connections that are not trapped have the sides of the pipe comparatively free of deposits and bacterial growths. There are still some differences of opinion in this regard, but it is believed that it would be of material assistance for plumbing codes hereafter to call for untrapped house connections.

Non-subsiding Velocities.—Many of the old sewers, both in this country and abroad, were of such a design that the sewage flowing through them deposited more or less of its suspended matters, including some of a fecal nature. This is probably much more true of the so-called "combined" sewers, which convey both storm water and sanitary sewage, than of the separate sewers, which convey sanitary sewage alone. This is noticeable where large storm sewers, in times of rain, discharge very foul matters for some minutes following an increase in flow. It is not at all unlikely that, during the interval elapsing since the last preceding storm, some organic matter may have become stranded upon the interior of the sewer under conditions such as to promote anaerobic decomposition. It is possible that putrefaction may

result to an extent that exercises considerable unfavorable influence on the broad question of sewage disposal without odors.

Increased attention should be given to the cleaning of catch basins frequently and thoroughly. It is of interest to mention here that Mr. C. D. Hill, Superintendent, Bureau of Sewers, Chicago, states in a report printed in the *Journal of the Western Society of Engineers*, September, 1911, that he favors a separate system for the "loop" district of that city, the storm sewers to be built without catch basins, and a grit chamber to be built at the outlet.

Smooth Interior Surfaces.—Where the interior surfaces of the sewers are rough and where projecting masonry allows deposits to be built up in front of it, it is quite possible that in these deposits anaerobic conditions are established in a manner and to an extent that is much more conducive to objectionable odors than is generally considered in this country by those who deal with reasonably well-designed and constructed sewers. The formation of enzymes may do much more toward bringing about putrefaction than hitherto realized in this country. German investigators believe this to be true where they have studied old combined sewers.

Flushing.—First-class sewerage practice calls for the installation of flushing tanks at the head of all sewer lines in order to wash away stranded particles of fecal matter in those portions of the sewer where the ordinary flow is insufficient to maintain a scouring velocity. Such flushing is sometimes done by automatic flush tanks discharging every few hours. From the bacteriological standpoint, it would probably suffice to have flushing done once a week during the cold season of the year and say twice a week or oftener in the warmer season of the year.

In the larger sewers it is not feasible to flush readily from automatic flush tanks, but it is practicable to keep decomposing organic matter from remaining lodged upon the interior surface of the sewers. This may be done either by hand, with a hose, or flush gate, or by putting in stop-planks at manholes and allowing the sewage to build up in depth until a head is established sufficient to create a scouring velocity when released.

Seeding.—The statements above are sufficient to point out the advantage of having clean sewers. They do not fully exploit, however, the possible disadvantage of deposits within a sewer system becoming seeded with suitable bacteria so that where

sufficient time elapses anaerobic decomposition may progress to the point of producing putrefactive enzymes. It is not difficult to consider conditions where stranded solid matters yield such putrefactive enzymes as may modify prejudicially the character of fairly fresh sewage flowing over such deposits. The character of the sewage may perhaps be modified by deposits in a system, having an extreme period of flow from the head of the sewer lines to the outfall of only an hour or two, so that the effect is more prejudicial than would be the case with a sewage that has flowed for five or six hours through clean sewers.

Aeration.—The introduction into sewage of more atmospheric oxygen than is left in the water supply of which the sewage was initially composed has perhaps more merit than has generally been considered hitherto for some large trunk sewers. While this would not provide substantial oxidation of organic matters, or increase the oxygen beyond the saturation point, it would afford the advantage of prolonging bacterial operations on an aerobic basis. From the standpoint of the "oxygen balance" it would make the sewage more stable. This aerating idea is unwittingly availed of in sprinkling filters within certain limits, and constitutes one of the reasons why sprinkling filters have a greater capacity per unit volume of filtering material than contact filters. The question will be taken up later in connection with the recent report of Col. Black and Prof. Phelps with respect to aeration of sewage as a means of treatment for certain districts within the city of Greater New York.

NATURE OF OBJECTIONABLE SEWAGE ODORS

Recognizing the necessity of considering anaerobic decomposition, on account of inability to control absolutely the decomposition of sewage on an aerobic basis, it becomes important to study the decomposition products in their relation to objectionable odors.

It has been noted already that, as transitional or end products of sewage decomposition, there are a number of foul-smelling substances. They appear in part as gaseous products and in part as compounds in solution. We do not pretend to know minutely as to their origin or appearance in sewage, but offer a few comments as to their characteristics as follows:

Non-gaseous Compounds.—While sulphureted hydrogen seems to have the reputation of being the most offensive product in the

decomposition of sewage, it is doubtful if this statement is correct. Indol, skatol, cadaverin, mercaptan, and some other compounds are considered more repulsive than sulphureted hydrogen. Indol and skatol are found in fresh feces, and no doubt show themselves at times in sewers and sewage disposal works. All of the products mentioned in this paragraph other than sulphureted hydrogen are found in sewage only in a soluble non-gaseous state.

The sense of smell is related to the effect which gases or vaporized substances produce on entering the nostrils and coming in contact with the nerves there. This is of importance in considering the question of odors. It is not to be inferred, however, that indol and other non-gaseous products are to be left out of the reckoning. They may make their influence felt, as is true of other liquids which are malodorous, by volatilization and evaporation. We will not attempt to enter further into this question, but it should be pointed out that floating scum and deposits which are exposed from time to time may release non-gaseous substances in a way to contribute substantially to the production of bad smells.

Gaseous Products.—Hydrogen, nitrogen, methane or marsh gas, and carbon dioxide are not considered objectionable gases as to odor production. Ammonia may become offensive, but rarely from the concentrations found in the atmosphere around sewage works. This leaves hydrogen sulphide as the particular gas to be considered here. Perhaps phosphine should be included.

Oxygen seems to be an antidote for sulphureted hydrogen to a considerable extent. More definite information than is now available is needed as to the chemistry and physics of these gases.

It will be well to point out some of the physical characteristics of those gases which are related to sewage decomposition, although sulphureted hydrogen is the only malodorous one of the group. A comparison of the characteristics of this gas, however, with others found in the decomposition of sewage will tend to accentuate the characteristics of the gases. Particularly, it is important to note the density and relative diffusive power of the gases and the volume and weight of the gases necessary for saturation under different conditions of temperature and pressure. These features are touched upon in the three following tables with respect to pure water, but without the influence of

the several gases upon each other or of the impurities which are dissolved in the sewage, all of which are factors of importance and about which our knowledge is meager at present. Rapid strides, however, in physical chemistry in recent years ought to permit these questions to be solved without great difficulty, so as to facilitate the proper consideration of these features.

TABLE 26.—TABULATION OF SOME PHYSICAL FEATURES OF THE GASES OF SEWAGE DECOMPOSITION

Gas	Weight of one liter (grams)	Density		Relative diffusion (Air = 1)	Vapor Tension in Atmospheres at 15°C. (Water Vapor = 0.017
		Air = 1	Hydr. = 1		
Hydrogen	0.090	0.0696	1.00	.3.83	.....
Methane	0.716	0.554	7.97	1.34	.....
Ammonia	0.762	0.762	8.59	1.29	7.13
Nitrogen	1.254	0.967	13.92	1.01	.....
Oxygen	1.429	1.105	15.90	0.95	.....
Hydrogen sulphide	1.523	1.189	17.10	0.95	16.4
Carbon dioxide	1.965	1.529	22.00	0.81	52.1

TABLE 27.—TABULATION SHOWING THE APPROXIMATE VOLUMES OF DIFFERENT GASES (PURE) OF SEWAGE DECOMPOSITION WHICH ARE REQUIRED TO SATURATE ONE VOLUME OF PURE WATER AT DIFFERENT TEMPERATURES AND PRESSURES

Gas	Atmospheric pressure		Pressure of 30 ft. of water	
	4° C.	15° C.	4° C.	15° C.
Hydrogen	.02064	.01883	.0405	.0365
Methane	.04985	.03874	.09065	.0751
Ammonia	941.9[2]	727.2[2]	.....	.....
Nitrogen	.02130	.01682	.0413	.0326
Oxygen[1]	.04397	.03415	.0852	.0664
Hydrogen sulphide	4.044	3.233	7.830	6.272
Carbon dioxide	1.513	1.002	2.943	1.942

[1] This is for pure oxygen, not atmospheric oxygen.
[2] Due to formation of NH_4OH.

TABLE 28.—TABULATION SHOWING THE APPROXIMATE WEIGHT IN PARTS PER MILLION OF DIFFERENT GASES OF SEWAGE DECOMPOSITION WHICH ARE REQUIRED TO SATURATE PURE WATER AT DIFFERENT TEMPERATURES AND PRESSURES

Gas	Atmospheric pressure		Pressure of 30 ft. of water	
	4° C.	15° C.	4° C.	15° C.
Hydrogen	1.86	1.69	3.61	3.27
Methane	35.65	27.7	69.15	53.7
Ammonia	792,000[1]	611,000[2]		
Nitrogen	26.70	21.1	51.8	40.9
Oxygen[1]	62.8	48.8	121.8	94.5
Hydrogen sulphide	6160	4930	11,950	9560
Carbon dioxide	2975	1965	5760	3810

[1] This is for pure oxygen, not atmospheric oxygen.
[2] Due to formation of NH_4OH.

In the discussion of Mr. Charles Saville's paper on the Imhoff Tank in the *Journal of the Association of Engineering Societies* for July, 1911, the foregoing data were offered by the author for discussion and a number of interesting features were developed. Several comments of importance came from Mr. Langdon Pearse and his associates at the Chicago sewage testing station. In particular, mention was made by Mr. Morrill that odors may be produced from solutions of hydrogen sulphide when they are far below the saturation point. This is due to the fact that saturation values are given for conditions where the liquid is overlaid with an atmosphere of the gas in question. When the gas is contained in solution and the ordinary atmosphere above it is free of the gas in question, then there is a gradual, and eventually a complete, diffusion of the gas from the liquid into the atmosphere.

Another point of value in the discussion of the foregoing paper was brought out by Dr. Spillner, who states that the sulphur-containing products of digestion processes are to be found in the urine or in the finely suspended, colloidal or dissolved organic matters, as distinguished from the coarse suspended matters which subside readily. This matter will be

touched upon later in connection with sedimentation tanks, but it is of interest here in giving some clue to the origin of the odor producing hydrogen sulphide.

It would be of interest if we knew more about this gas and whether it is in reality a product which occurs as such in sewage to a considerable extent, or whether it is mixed with mercaptan and other products which smell badly. Mercaptan is a sulphur compound (C_2H_5SH), but sulphur is not found in indol, skatol, nor other products mentioned in the group of non-gaseous odor-producing compounds of decomposition.

Phosphorous may afford offensive decomposition compounds, but we are not informed about them. In his recent book on Microbiology, page 128, Prof. Marshall states that there must be a "cycle" for phosphorus, similar to the sulphur cycle. Phosphine (PH_3) is a foul smelling gas, as mentioned on pages 80 and 84.

CONTROL OF SULPHURETED HYDROGEN ODORS

There is no known way of preventing the formation of sulphureted hydrogen, which is released from organic sewage matters by a great variety, and perhaps most kinds, of bacteria. So long as it is released in oxygen-containing water complications do not seem to be serious, unless the conditions of decomposition are such that the gas is released so that numerous tiny bubbles, saturating their immediate surroundings, mass together into large bubbles, the buoyancy of which causes them to rise to the surface of the liquid.

There is apt to be quite an irregular dispersion of organic sulphur compounds in sewage. This feature may perhaps be quite important in explaining irregularities in the release of objectionable smells from certain sewage disposal devices. There is good reason to believe that to some extent sulphureted hydrogen is characteristic of all sewage decomposition. It does not seem true that certain bacteria decompose sewage with the formation of marsh gas and no hydrogen sulphide, while other bacteria produce sulphureted hydrogen and no marsh gas. There may be certain conditions under which offensive gases may be released from certain operations, but not under other conditions. These comments are made, having in particular view the observation that some disposal plants produce noticeably objectionable odors on half a dozen days or nights in

the course of the year, and are practically free of such odors during the balance of the time. It is, therefore, necessary to increase our energies in the study of the special conditions which occasionally prove bothersome.

Associated with the above-mentioned factor is the condition of the atmosphere at times when the odors are most noticeable as to intensity and distance from the works. Aerial nuisances as to odor vary much with the barometric conditions and wind velocity, as they affect the dispersion and oxidation of gases in the atmosphere. Thus, at many disposal plants it is found that objectionable odors are most noticeable as to intensity and distance from the plant on what are ordinarily spoken of as "muggy" days. The barometric pressure on such occasions no doubt prevents the gases, particularly a heavy one like sulphureted hydrogen, from rising as high in the atmosphere as ordinarily is the case. Furthermore, the dispersion of the gases in the atmosphere is much less rapid than usual and this perhaps prevents aerial oxidation at normal speed. Associated with this are no doubt a variety of other factors about which information is quite meager at present. It is perhaps worth mentioning that some of the malodorous products may not be present in a chemical state such as to promote oxidation. They may be combined with other compounds which retard the reaction with the oxygen of the air.

Regarding this subject it will perhaps be well to speak briefly of the fact that at some disposal plants there are characteristic odors other than that of products of anaerobic decomposition. These odors are sometimes spoken of as being similar to laundry odors or odors resembling a raw turnip. The odor of cooking of certain vegetables is, of course, a conspicuous one under some circumstances. It is mentioned here to accentuate the thought that there are a good many decomposition products which have an individuality which is not specifically offensive, although it is noticeable and objected to by some. At the same time, such products suggest that hydrogen sulphide is not the whole story, and that it is important to study other compounds in connection with the question of objectionable odors, now classified for convenience as "hydrogen sulphide." Several features concerning the control of this type of odor will now be outlined.

Arresting Sulphate Reduction.—In the event that it is true that there are but very few species of bacteria capable of pro-

ducing hydrogen sulphide through the reduction of the mineral sulphates, it may be feasible to find some way of destroying such growths. It would be better yet to find means of preventing such growths from becoming seeded in works, on account of the importance of guarding against the resulting solvent actions that disintegrate masonry and metal structures. It seems to be a fruitful field for the laboratory man to develop.

Bacterial Cultivation.—Not in sewers but under some conditions it may be feasible to cultivate *Beggiatoa* and *Thiothrix* which are capable of consuming hydrogen sulphide. The quotation given in Chapter II from Lafar indicates that the zone of their successful growth would be within quite narrow limits.

Concentration and Mixing.—Within certain limits it is feasible to minimize the opportunities for bacterial decomposition to produce a large quantity of sulphureted hydrogen at the same point or location. This refers not only to sewage works, but to streams and estuaries where sewage deposits have to be reckoned with. The matter will be touched upon later. It involves the question of thorough mixing, so far as practicable, of decomposing substances, and of overlying liquids. The object is to have the hydrogen sulphide formed under conditions most favorable to ready control by oxidation and precipitation.

Precipitation.—Sulphide of iron is a black precipitate which explains the dark color of most of the stale and septic sewages. The precipitation of this gas by iron liquors and the iron naturally contained in sewage has an important bearing upon the odor question. As stated by Mr. Morrill, the precipitation of hydrogen sulphide will not necessarily be complete at all times, so as to prevent all escape into the atmosphere, particularly where bubbles of large size are evolved. However, it is believed that it is of much importance to the actual performance of some disposal plants, such, for instance, as at Birmingham, England. There is no reason, apparently, why iron salts should not be added in a manner to control the precipitation of this gas if need be.

Other Combinations.—Hydrogen sulphide may unite with ammonia compounds to form ammonium sulphide which is soluble but not gaseous. Possibly carbon dioxide combines with hydrogen sulphide under some circumstances; at least it has been suggested that carbon bisulphide is formed. All of these matters need further elucidation.

Oxidation in Liquids.—Oxygen-containing water minimizes the effect of this gas in sewers, sewage tanks, streams, and the like. It furnishes an opportunity for control, and the greater the depth of the overlying liquid the greater will be the opportunity for preventing gas bubbles rising to the surface. Further, at considerable depths from the surface the coefficient of absorption of gases by water is greater, and this tends to minimize the appearance of gas at the surface of the liquid.

SANITARY SIGNIFICANCE OF OFFENSIVE ODORS—ISOLATION

Offensive odors from sewage relate for the most part to the aesthetic and not the sanitary side of the question. It is true that some people are nauseated and perhaps debilitated by putrid odors. But the general evidence now indicates that these odors do not produce sickness to an extent materially affecting the death rate in a community. All reasonable effort should be made, however, to prevent the occurrence of bad odors.

Wide differences of opinion exist with respect to odors from sewage and sewage works. Some people are so constituted that even fresh sewage conveys to them the idea of an unmitigated nuisance. Some people actually take offense to the flow of ground water (seepage) in an outfall sewer to which no house connections have been made, in a manner similar to the sentimental objections to operating garbage incinerators while they are being dried out through the burning of coal, and before a single shovelful of garbage has been delivered to the plant.

On the other hand, there are those who are accustomed to the odors of manured fields, fish markets, meat markets, cheese factories, etc., and to whom the odor of sewage makes quite a different impression. Included, perhaps, in the latter class are those who have much to do with sewage works.

It is certain that sewage outfalls and sewage-treatment works are not likely to smell like a flower garden, unless more attention than has ordinarily been the case hitherto is given to minimizing sewage odors and increasing the extent of the landscape gardening.

Where feasible, isolation is desirable. When it is not feasible to isolate disposal works they should be designed and operated with the specific view of guarding against offensive odors. Methods are available for eliminating the decomposing portions

of sewage so that it is not exposed to view until in a stable or humified condition.

RÉSUMÉ

Sewage bacteria through decomposition processes may produce offensive odors unless the latter are prevented or controlled. So far as feasible decomposition of sewage should proceed on an aerobic and not an anaerobic basis. This applies in particular to stranded solids which may give off enzymes that affect the overlying sewage far more than hitherto supposed.

The collecting sewers should be well ventilated throughout and have smooth interior surfaces and non-subsiding velocities. When and where necessary flushing should be provided to guard against deposits within the sewers and other water ways.

There are several decomposition compounds both gaseous and non-gaseous which give off offensive odors. They have been loosely classified as hydrogen sulphide, but this does not tell the whole story. So far as sulphureted hydrogen is concerned, there is much that can be done to prevent or control its appearance. Oxidation and precipitation are perhaps the most useful means of control.

While odors are not productive of great influence upon the public health, their presence around disposal works should be minimized so far as practicable unless the plant is very well isolated. The whole question needs careful study in each instance as regards the location of the plant and its design, construction and operation.

CHAPTER IV

SEWAGE BACTERIA AS RELATED TO PUBLIC WATER SUPPLIES

Sanitarians find, naturally enough, with present conceptions of the germ theory of disease, that sewage-polluted water supplies serve as a vehicle for the transmission of certain diseases. These are called the water-borne group, the specific germs of which leave the human body through the feces or urine and pass through sewers to streams serving as public water supplies. Persons who sicken of these diseases receive the infection through the mouth with the water they drink.

Typhoid fever and Asiatic cholera are conspicuously the best-known water-borne diseases. The history of their transmission, however, does not tell the full story as to the damage done by sewage polluted water supplies, nor, on the other hand, is the public water supply the only vehicle for transmitting these diseases. It is not the intention here to enter at all deeply into the fields of etiology and epidemiology. But in order to accentuate the seriousness of sewage pollution of water supplies, and the necessity either of preventing or removing such pollution, it is desired briefly to record some of the more salient evidence upon the subject.

WATER TRANSMISSION OF CHOLERA AT HAMBURG

In 1892, the river Elbe, from which at that time the city of Hamburg, Germany, took its water supply without filtration, became infected. Dr. Reincke, health officer of Hamburg, in his 1892 report says:

> The epidemic began on August 16, in the port where earlier outbreaks have also had their origin. The original source of the infection has not been ascertained with certainty, but was probably from one of two sources. Either it came from certain Jews, just arrived from cholera-stricken Russia, who were encamped in large numbers near the American pier, or the infection came from Havre, where cholera had been present since the middle of July. Perhaps the germs came in ships in water-ballast which was discharged at Hamburg. This is plausible, as the sewage of Havre is discharged directly into the docks.

A severe epidemic of cholera broke out in Hamburg having then a population of about 640,000. It continued for several months, during which there were more than 17,000 cases, with a total death list from this disease of about 8600.

The adjoining city of Altona also drew its water supply from the river Elbe, from an intake located about seven miles below the Hamburg sewers. The Elbe water furnished to Altona was carefully filtered, with the result that there was only about one-sixth as high a death rate from this disease in Altona as in Hamburg during the time that the latter city suffered so severely. Those cases and deaths that did occur in Altona were understood to have been contracted in Hamburg, with the infection thus carried home overland, and not by way of the Hamburg sewers and the Altona water supply. Another suburb of Hamburg, Wandsbeck, contributed valuable data also, in that it enjoyed as low a death rate from the cholera during Hamburg's affliction as did Altona. This was accounted for by the fact that Wandsbeck's water supply was not from the Elbe.

The above experience is only one of many to show conclusively that the germs of Asiatic cholera are water-borne and that sewage containing such germs is a most powerful menace when forming a slight portion of an inadequately-treated water supply.

TYPHOID FEVER AS CAUSED BY POLLUTED WATER SUPPLIES

It is, perhaps, unnecessary to do more than to point out here the striking fact that when sewage-polluted water supplies have been replaced by supplies of substantial purity, either through the introduction of good filters for treatment of the polluted supply, or the substitution of ground water or different surface waters, there has been a striking reduction in the typhoid fever death rate. This was noted conspicuously at Hamburg, Zurich, and numerous places in Europe.

Equally striking statistics were obtained at Lawrence, Mass., and Albany, N. Y., when filtration plants were introduced for treatment of the highly-polluted waters of the Merrimac and Hudson rivers, respectively. Similar statistical data were obtained at Lowell, Mass., when the polluted Merrimac water supply was abandoned and there was substituted therefor a ground-water supply of good quality. Similar data, furthermore, were obtained at Newark and Jersey City, N. J., when the highly-polluted Passaic river at Belleville, N. J., below the

sewers of Paterson and Passaic, was abandoned in favor of upland waters of good quality, generally speaking.

Table 29 indicates the extent of the reduction in typhoid following the installation of a number of well-known filter plants in this country:

TABLE 29.—ANNUAL AVERAGE DEATH RATES FROM TYPHOID FEVER PER 100,000 POPULATION

City	Plant completed	Years in average		Typhoid fever death rates	
		Before filtr.	After filtr.	Before filtr.	After filtr.
Mechanical Filters					
Binghamton, N. Y.	1902	5	5	47	15
Cincinnati, Ohio	1907	4	4	50	12
Columbus, Ohio	1908	11	3	78	11
Hoboken, N. J.	1905	7	6	19	14
Paterson, N. J.	1902	5	9	32	10
Watertown, N. Y.	1904	5	7	100	38
York, Pa.	1899	2	12	76	21
Sand Filters					
Albany, N. Y.	1899	9	9	74	22
Lawrence, Mass.	1893	7	15	114	25
Washington, D. C.	1905	5	6	57	33

WASHINGTON, D. C., EXPERIENCES

That reductions in typhoid fever death rates, following the introduction of efficient filters, do not always follow promptly, is well exemplified by the experience at Washington, D. C., where a well-built sand filter plant has been carefully operated without interruption since October, 1905. The full method recommended for the treatment of the Potomac water embodied a coagulating department with which to reduce excessive turbidity before the water reached the sand layers. Notwithstanding occasional periods of turbidity in the filtered water, the bacteriological results from the Washington plant show a high grade of filtered water from the laboratory standpoint.

The vital statistics of the District of Columbia did not show at once substantial reductions of the typhoid fever death rate and the general death rate. This caused careful investigations of the subject to be made in the Hygienic Laboratory of the Public Health and Marine Hospital Service of the United States. Three reports upon the origin and prevalence of typhoid fever in the District of Columbia were prepared by Drs. Rosenau, Lumsden and Kastle. These valuable reports appear as Bulletins 35, 44, and 52 of the hygienic laboratory above mentioned. From the latter bulletin, appearing in October, 1909, the following extracts have been taken as illustrative of the vital statistics of the District of Columbia in their relation to improvements in the water supply; resulting, first, from the installation in 1902 of the large Washington city storage reservoir, and secondly, from the sand filtration plant put in service in October, 1905. The final summary is of value in keeping clearly in mind the fact that sewage pollution and disease germs coming from sewage do not, by any means, account for the transmission of all of the water-borne diseases. Later statistics show much lower death rates from typhoid fever, and we added the data for 1909, 1910 and 1911, in the tabulations. The text of the quotations applies only to the data ending with 1908.

TABLE 30.—ANNUAL DEATH RATES PER 100,000 FROM TYPHOID AND CERTAIN OTHER DISEASES IN THE DISTRICT OF COLUMBIA

Year	Pneumonia	Pulmonary tuberculosis	Scarlet fever	Diarrhea and enteric diseases			Typhoid fever
				Under two yrs.	Two yrs. and over	Total, all ages	
1900...	137.7	278.9	4.4	131.9	26.2	158.2	74.1
1901...	130.5	271.0	3.7	114.8	27.4	142.2	56.4
1902...	156.5	224.6	2.0	107.7	30.5	138.2	74.0
1903...	179.6	249.2	0.6	90.6	30.2	120.8	45.0
1904...	175.2	262.3	3.5	101.8	20.8	122.6	43.8
1905[1]...	164.1	255.6	3.4	104.3	23.5	127.8	43.9
1906...	154.1	239.2	2.5	97.4	23.6	121.0	49.3
1907...	163.5	226.9	0.6	98.6	23.7	122.7	34.5
1908...	150.2	208.9	2.6	97.5	18.8	116.3	36.5
1909...	174.0	218.0	8.0	.....	....	93.0	33.0
1910...	174.0	219.0	3.0	.....	....	105.0	23.0
1911...	166.0	204.0	1.0	.....	....	92.0	21.0

[1] Water filtered October, 1905.

It will be observed that, with the exception of pulmonary tuberculosis, the death rate of which has gradually but progressively declined since 1904, there has been but little difference in the death rate from these diseases since the water supply of the city has been filtered (October, 1905). Some decrease in the death rate from diarrheal diseases is noted. The average rates for the three years 1903–05 was 124, and for 1906–08 was 120.

The death rate from all causes per 1000 of population in the District of Columbia has been as follows:

Year	Death rate
1900	20.61
1901	20.19
1902	18.95
1903	19.09
1904	19.61
1905	19.20
(Water supply filtered October, 1905)	
1906	19.35
1907	19.25
1908	18.03
1909	18.12
1910	18.69
1911	17.80

For the three years 1900 to 1903 the average of the annual death rates from all causes was 19.92 per 1000. For the three years 1903 to 1906, the average of the annual rates was 19.30; for the three years 1906 to 1909—that is, after the filtration of the public water supply—the average of the annual rates was 18.88. Thus the reduction in the death rate from all causes since 1900 has been progressive.

There was a greater reduction in the rate between the 1900–03 and 1903–06 periods than between the 1903–06 and 1906–09 periods. So it is questionable how much of the reduction in the last three years has been due to the further improvement in the city's water supply by sand filtration. In this connection it should be remembered that an additional storage reservoir (Washington City) was put into operation in 1902.

These data are presented for what they are worth, in view of Hazen's theorem:

For every death from typhoid fever avoided by the purification of public water supplies two or three deaths are avoided from other causes. (Sedgwick and MacNutt. *Science*, Aug. 14, 1908, page 215.)

In 1907 and 1908 the high typhoid fever rate continued until the cessation of warm weather; in 1906, however, there was a very marked decline in the typhoid fever rate eight weeks before the marked decline in the warm weather, indicating that in this year some factor or factors independent of warm weather per se operated to a relatively greater extent than in 1907 and 1908.

Geographical Distribution.—During the three years there has been a general and fairly uniform distribution of cases throughout the city.

Sanitary Conditions.—The majority of the cases occur among persons who live in houses of good or fairly good sanitary condition. In 1907 and 1908 the proportion of cases among persons living under the best sanitary conditions was much smaller than in 1906.

Sewerage System.—There is little difference in the prevalence of the disease in the sewered and in the non-sewered districts. There has been no especial grouping of cases, nor an excessive prevalence of the disease in the sections of the city in which a number of privies remain.

Flies.—In a well-sewered city, as Washington now is, flies would not be expected to play much of a part; and the lack of correlation between the seasonal curve of fly abundance and that of typhoid fever seems to corroborate this view.

Servants.—The majority of the cases occur in households without servants. There is no evidence to support the supposition that day servants frequently convey infection to the households of their employers.

Imported Cases.—With the decreased prevalence of the disease in 1907 and 1908 the relative percentages of imported cases have increased, but the actual number has remained practically the same during the three years.

Contact.—Our studies again show that "contact" is one of the major factors in the spread of the disease.

Bacillus Carriers.—The results of the examination of the excreta of about a thousand apparently healthy persons indicate that the typhoid bacillus is more commonly distributed among persons than the actual number of clinically recognized cases of the disease suggests.

Milk.—About 10 per cent. of the cases in 1908, as in 1906 and 1907, were definitely attributed to infected milk. In the 1908 outbreak the milk was infected by a bacillus carrier. Our studies for the three years indicate that if all the market milk of Washington were pasteurized under official supervision, the amount of typhoid fever here would be materially reduced.

Shellfish.—It is now evident that oysters and other shellfish do not play much part.

Water.—According to the accepted bacteriological standards, the filtered Potomac river water during the typhoid seasons of 1907 and 1908 was of good sanitary quality and it does not seem probable that

such water could have been directly responsible for much, if any, of the infection. There is not yet sufficient evidence, however, for a positive conclusion to be drawn as to just what part the Potomac river water has played in the causation of the disease in previous years.

Washington's "Excessive" Typhoid Fever Rate.—Considering the climatic and general sanitary conditions of Washington, the typhoid fever rate is still comparatively high for a city with no water-borne infection.

Prophylaxis.—The results of three years of study show that the disinfection of excreta of patients is frequently inefficient or neglected, and that there is a need of legal control of typhoid fever patients and typhoid bacillus carriers.

We are convinced that a vigorous campaign against typhoid fever as a "contagious" disease, and the adoption of measures that would prevent the spread of the infection in milk, would eliminate the greater part of typhoid fever from the District of Columbia.

COMMENTS OF DR. WOODWARD.

It is through the kindness of Dr. William C. Woodward, Health Officer of the District of Columbia, that the author is enabled to include in the above tables the vital statistics through the year 1911. Dr. Woodward has also expressed his views in a communication to the author relative to the conclusions quoted above from the Public Health and Marine Hospital Service. With some of these conclusions he is in thorough accord, but with others he is inclined to take a somewhat different viewpoint.

As to milk, he states that the data considered in the bulletin above did not cover the entire 12 months of any year. Such investigations have been made by him during the full year for a number of years. The results do not support the statement that 10 per cent. of the cases of typhoid fever are attributable to milk, but indicate that not more than 2 to 4 per cent. can be demonstrably so attributed.

Regarding typhoid carriers and the suggestion that apparently healthy persons may distribute these bacilli, it is pointed out that the conclusion quoted above is indefinite. On the score of prophylaxis and the suggestion of needed legal control of typhoid fever patients and typhoid bacillus carriers, Dr. Woodward states that upon the issue of the above report the Surgeon-General of the U. S. Public Health and Marine Hospital Service was requested to indicate wherein the existing laws and regulations of the District of Columbia pertaining to typhoid fever could with advantage be amended. Although several years

have elapsed, no suggested amendments have been offered. Theoretically such steps tend to eliminate typhoid fever, but the practical difficulty of course is in the enforcement of laws that undertake to regulate the conduct of an individual within his own home.

WATER SUPPLY AS RELATED TO TYPHOID AND GENERAL DEATH RATES

THE HAZEN THEOREM

Quotations in the foregoing Washington reports suggest that the filtration and improvement of polluted water supplies may result in the reduction of the general death rate to an extent greater than is accounted for by the reduction in the death rate from typhoid fever.

Independently of each other this fact was noted in 1893–94 by Mr. Hiram F. Mills, the engineer member of the Massachusetts State Board of Health, and by Dr. J. J. Reincke, Health Officer of Hamburg, Germany. Mr. Mills studied the vital statistics of Lawrence, Mass., before and after the introduction of the sand filter plant at that city on September 20, 1893. Dr. Reincke studied corresponding statistics for Hamburg following the introduction of the sand filter plant for the polluted Elbe supply on May 27, 1893.

Mr. Allen Hazen set forth these facts concisely and forcibly in a paper (*Transactions, American Society of Civil Engineers*, Vol. LIV, Part D, page 152), presented to the International Engineering Congress at St. Louis in 1904. The importance of this subject is such that Mr. Hazen's statements as to the effect of an improved water supply are set forth at length as follows:

TABLE 31.—DEATHS FROM ALL CAUSES PER 1000 PER ANNUM

Place	Date of change	Five years before change	Five years after change	Percentage of reduction
Hamburg, Germany, filtration	1893	24.0	17.7	26
Lawrence, Mass., filtration	1893	24.4	20.0	18
Albany, N. Y., filtration	1899	22.3	18.4[1]	17
Newark, N. J. river water to upland water.	1892	25.1	22.1	12
Jersey City, N. J., river water to upland water.	1896	25.4	19.3	24
Lowell, Mass., river water to ground water	1895–96	25.1	20.5	18
Average		24.4	19.7	19

[1] Four years.

While the reduction in the typhoid rate is 66 per 100,000 that in the general death rate is 4.7 per 1000 or 470 per 100,000, or seven times as much. Where there is one less death from typhoid fever there are six less from other causes.

The writer believes that the whole of the reduction in the typhoid rate should be attributed to the change in water supply, because cities similarly situated, which have not improved their supplies, have experienced no permanent reduction in their typhoid fever rates. With the general death rate the case is different. Improved general sanitary conditions have reduced the death rates in recent years, and the normal reduction in a period of six years, which represents the average elapsed time between the first and second series of results, would account for a part of the reduction in the general death rate.

The average reduction in the general death rate between 1890 and 1900 in eighteen cities having from 50,000 to 300,000 inhabitants, in New England, New York, and New Jersey, which made no radical change in their water supplies, was 2.28 per 1000. This is computed from the report on Vital Statistics in the United States Census of 1900. Assuming a uniform decrease in rate in the interval, the average, or what we may call the normal, reduction, in 6 years would have been 0.6 of this, or 1.37 per 1000. In comparison with this, in five cities where the water was radically improved, the reduction in the same period was 4.4 per 1000. The results may be tabulated as follows:

	Death rate per 100,000 living.
Reduction in total death rate in five cities with the introduction of a pure water supply	440
Normal reduction due to general improved sanitary conditions, computed from average of cities similarly situated but with no radical change in water supply	137
Difference, being decrease in death rate attributable to change in water supply	303
Of this, the reduction in deaths from typhoid fever was	71
Leaving deaths from other causes attributable to change in water supply	232

This computation indicates that where one death from typhoid fever has been avoided by the use of better water, a certain number of deaths, probably two or three, from other causes have been avoided. This seems the clear and logical conclusion from the statistics. It is not easy to explain how the water is connected with the deaths other than those from typhoid fever. It may be that a good water supply, used freely,

and with confidence, results in a better general tone in the systems of the population, and so indirectly in a lower death rate, and that a part of the reduction is represented by diseases having no recognized connection with the quality of the water supply.

SEDGWICK'S AND MACNUTT'S STUDIES

Prof. William T. Sedgwick, the well-known epidemiologist, of the Massachusetts Institute of Technology, in conjunction with a former student, who later was Health Officer of Orange, N. J., Mr. J. S. MacNutt, has given this question much study and recorded the results in a valuable paper appearing in the *Journal of Infectious Diseases* for August, 1910.

The historical development of the data in question is clearly set forth under the nomenclature of the Mills-Reincke phenomena. Mr. Hazen's conclusions are referred to as "Hazen's theorem," briefly stated as follows:

Where one death from typhoid fever has been avoided by the use of better water, a certain number of deaths, probably two or three, from other causes, have been avoided.

Messrs. Sedgwick and MacNutt made a detailed study of the mortality statistics, not only of Lawrence and Hamburg, but also of Lowell, Mass., Manchester, New Hampshire, and Albany, Binghamton and Watertown, New York. Manchester was studied in order to throw light on the data, by virtue of similarity in location and character of population, and with a relatively pure water supply furnished without filtration from upland sources. Lowell was studied not only on account of its being a neighboring city to Lawrence and similar in character of population, but also because it abandoned the polluted Merrimac river water and substituted a pure ground-water supply at about the same time that filters for the Merrimac river water were completed at Lawrence. Additional information was sought from cities in New York state for the influence of water purification, Albany, N. Y., having adopted a sand filter plant for the highly-polluted Hudson river water, and Binghamton and Watertown N. Y. because of their adoption of mechanical filter treatment of polluted supplies. At Watertown, the improvement in the typhoid and the general death rates was not so striking following the introduction of filtered water as at the other places mentioned. This seems to be explained to the probable inefficiency of the filter plant of Watertown, according to the authors.

In the supplement of *Engineering News* of December 15, 1910, page 62, there is given a concise review of this paper. We quote from the paper as follows:

Mr. Hazen's quantitative expression for the Mills-Reincke Phenomenon, when applied to the cities which we have studied (with the exception of Watertown) appears sound and conservative. It seems likely, however, that it will be impossible in the future to confine the relation even within the broad numerical limits suggested by Mr. Hazen. In fact, Mr. Hazen himself is very careful in this particular, as will be seen by a reference to his original statement. It is probable that the pollution of a public water supply may consist, at one time or in one place, of much typhoidal infection mingled with comparatively little sewage, or, on the other hand, of much sewage only lightly charged with typhoid fever germs. In the former case the reduction in typhoid fever might be out of all proportion to the reduction in general death rate, and in the latter case *vice versa*. For Hamburg, we have pointed out above, that the saving in typhoid mortality was slight in comparison with the saving of mortality in other diseases, combined, *i.e.*, roughly only about 1 to 16. In the other cities studied, we find rates widely different from this, *e.g.*, at Lawrence, 1 to 4.4, at Lowell, 1 to 6.0, in Albany, about 1 to 4.1 (uncorrected), and in Binghamton only about 1 to 1.5 (uncorrected). It is clear, therefore, that Hazen's theorem is merely a convenient formula rather than a precise mathematical expression.

One of the most surprising results of this study is the disclosure of the remarkable relation apparently existing between polluted water and infant mortality. Pure water showed a marked reduction. In a less marked degree this seemed true as regards diarrhea and gastro-intestinal disorders. As to tuberculosis it is stated that the evidence, though less striking, is interesting and suggestive. The data also seemed to show a marked relation in the decline of pneumonia and bronchitis, following the substitution of pure for impure water. Concerning the explanation of these observations the writers of this paper sum up as follows:

Finally, the question naturally arises, to what is the decline of mortality observed in the Mills-Reincke phenomenon for diseases other than typhoid fever due? A little reflection will show that increase of vital resistance, due perhaps to the use of purer drinking water, might produce this effect, while, on the other hand, the same results might be reached by an exclusion of disease germs formerly present and working upon the bodies of their victims. Or, as a third possibility, the phenomenon might be due to a combination and co-operation of these two factors.

It is interesting to observe that Mr. Mills in his writings upon this subject, without especially committing himself to either hypothesis, has apparently had in mind chiefly an increase of vital resistance, while Dr. Reincke has expressed himself rather as looking to the removal of disease germs previously present.

The facts at present in our possession do not allow us to settle the question beyond peradventure and this problem, like many others raised throughout our paper, requires further elucidation.

In considering the Hazen theorem above set forth it is, of course, necessary to bear in mind that its significance bears quite a definite relationship to the degree of sewage pollution of the water supply that is abandoned and later is compared with an improved supply, either from another source or from an original source after purification. This is particularly true in the instances above mentioned of the Elbe at Hamburg; the Merrimac at Lawrence and Lowell; the Hudson at Albany and the Passaic river at Belleville. In fact, it requires quite a stretch of the imagination to realize that it is only fifteen or eighteen years ago that Newark and Jersey City drew their water supply from the lower Passaic river, near Belleville, which for a dozen years or more has been regarded as an open sewer constituting a nuisance to the lower Passaic valley.

VARIATIONS IN DEATH RATES IN CITIES WITH THE SAME WATER SUPPLY

It by no means follows that a new supply or a filtered supply is of unsatisfactory quality just because the Hazen theorem does not assert itself conspicuously. In the opinion of the author, this is well exemplified by the vital statistics from Washington, quoted above. It is also shown by the vital statistics of those New Jersey cities that receive filtered water either from the Passaic river at Little Falls, N. J., or from the Hackensack river at New Milford, N. J. Paterson, Passaic and Bayonne have received filtered water from Little Falls since September, 1902, and Hoboken and Hackensack have been similarly supplied from New Milford since the late autumn of 1905. Table 32 shows some statistics prepared by the author recently from available State records. These statistics have a few irregularities as to differences in the statistical years but are sufficiently accurate for present illustrative purposes.

TABLE 32.—ANNUAL RECORD OF THE TOTAL DEATH RATE PER THOUSAND OF POPULATION AND OF THE TYPHOID FEVER DEATH RATE PER HUNDRED THOUSAND POPULATION, IN NEW JERSEY CITIES BEFORE AND AFTER RECEIVING WATER FROM MECHANICAL FILTERS

Date	Paterson		Passaic		Bayonne		Hoboken		Hackensack	
	Total	Typh.	Total	Typh.	Total	Typh.	Total	Typhoid	Total	Typhoid
1895–96	19.2	43	21.9	17	20.5	20	22.8	39	11.5	27[1]
1896–97	18.7	47	24.3	60	21.8	35	20.8	15	14.5	0
1897–98	15.9	35	19.8	58	25.0	29	18.1	12	11.4	0
1898–99	19.6	52	23.6	50	25.6	58	19.9	21	14.9	12
1899–00	18.7	28	21.0	36	17.4	12	23.0	32	13.7	21[2]
1901....	17.5	25	18.2	17	14.4	23	19.3	16	16.9	30
1902....	16.4	33	17.7	9	15.3	24	18.8	11	18.3	19
1903....	15.3	21	20.0	15	18.4	24	17.7	16	16.4	28
1904....	17.8	6	18.5	17	16.6	28	22.3	20	13.8	18
1905....	16.5	14	18.3	8	15.8	12	21.1	15	17.5	27
1906....	17.7	4	16.4	2	17.2	7	21.5	16	16.9	17
1907....	16.1	12	19.3	17	16.6	17	22.9	26	18.6	17
1908....	16.2	11	17.4	11	15.0	8	18.3	19	14.1	0
1909....	16.2	10	17.1	9	13.6	4	17.6	13	15.4	24
1910....	14.7	8	15.0	15	15.0	2	18.3	11	16.2	43
1911....	14.7	7	14.3	9	14.0	0	17.9	0	14.8	14

[1] 1896 Calendar year. [2] 1900 Calendar year.

In considering these statistics it is interesting to note the irregularities in the death rates, not only from typhoid fever but from all causes, in the different communities during the same year, where all are supplied with filtered water from the same source. This shows clearly the effect of other factors than the public water supply in influencing vital statistics on the so-called water-borne diseases.

Another factor is to be borne in mind in studying the New Jersey statistics with respect to these filtration plants. And that is that the opportunities for obtaining substantial reduction in death rates were lessened by the comparatively good quality of unfiltered water just prior to the introduction of the filter plants. In fact, neither the Little Falls nor New Milford filter plants was contemplated a few years prior to their adoption. Quite unusual efforts had been made previous to the change in policy to remove sources of pollution in the river water. The work was

carried out industriously on the Passaic watershed under the direction of Dr. J. L. Leal, and in the Hackensack watershed under the direction of Dr. E. J. Lederle. In the case of Paterson and Passaic, it is also worth bearing in mind that, some two or three years before the Little Falls filter plant was completed, the source of supply for these cities had been changed from Great Falls at Paterson to Little Falls, some four or five miles above. By so doing there was eliminated more or less local pollution. The significance of this is quite clear, as the transfer of the intake discounted considerably the improvement that filtration would otherwise have accomplished. This same remark applies, of course, to the general cleaning up of the watershed, both on the Passaic and the Hackensack.

In commenting upon the effect of improved water supply upon the vital statistics of Paterson and Passaic, Dr. Leal states that he knows of no well-established relation except as to typhoid fever and diarrheal diseases. Decreases in general death rate are found when a very grossly polluted water supply is changed to a good one. There is no scientific medical evidence, in his opinion, to explain such improvement in detail. The death rate of a community is liable to sudden and sometimes unaccountable fluctuations. This is true independently of the problem of water supply, as is well shown by the Paterson and Passaic death rates in neighboring manufacturing cities receiving the same public water supply during the period covered by the above statistics. In his judgment these facts relate to the thoroughness of the enforcement of efficient sanitary laws on the part of health authorities and to the appreciation on the part of the public of the principles of sanitary science.

VITAL STATISTICS OF CINCINNATI, OHIO

A less striking instance of the Hazen theorem is found in the introduction of a well-built and well-operated mechanical filter plant at Cincinnati, Ohio. It takes the Ohio river water from above the mouth of the Little Miami river near the village of California. It is some seven miles above the old intake adjoining the Front Street pumping station, near the heart of the city. Between the old and new intakes some 32 small sewers discharged into the river, as stated on page 12 of the author's report in 1899 upon Water Purification at Cincinnati.

TABLE 33.—ANNUAL NUMBER OF DEATHS FROM DIFFERENT CAUSES SINCE 1905 IN CINCINNATI, OHIO
(Bertillon Classification)

	1905	1906	1907	1908	1909	1910	1911
General diseases:							
Typhoid fever	155	239	157	64	45	21	43
Diphtheria and croup	78	77	56	54	38	.....	48
Dysentery	21	22	30	9	11	5	7
Cancer of stomach and liver	210	219	110	136	133	142	142
Nervous system:							
Meningitis, cerebro-spinal						13	15
Meningitis, simple	118	136	113	87	67	63	45
Convulsions of children	91	85	70	25	.....	.....	.....
Respiratory system:							
Bronchitis, acute	108	92	51	77	44	100	68
Pneumonia	594	505	419	423	382	388	288
Digestive apparatus:							
Affections of stomach (cancer excepted).	57	172	101	40	47	43	39
Diarrhea and enteritis (under two years).	361	342	205	329	318	378	271
Diarrhea and enteritis (over two years).	96	102	69	71	37	71	91
Peritonitis (puerperal excepted)	41	57	68	16	13	3	2
Urinary apparatus, etc.:							
Nephritis, acute	95	112	86	37	32	33	57
Old age:							
Senile debility	346	283	298	211	55	4	3
Total of all above	2371	2443	1833	1579	1222	1264	1119
Total, all causes	6534	7195	6414	6449	5921	6330	6224
Total death rate per 1000	19.1	20.8	18.5	18.5	16.7	17.3	16.2

Settled water from new intake since summer of 1907.
All water filtered since October, 1907.

The vital statistics in Table 33 have been taken from the records of the Cincinnati Board of Health. They show quite striking but irregular reductions, not only in the total death rate, but in the death rate from several diseases not touched upon in detail by Messrs. Sedgwick and MacNutt. How far these data tend to indicate a relation between sewage bacteria and the causation of the several diseases listed in the following table is a question that the author will not attempt to discuss. Perhaps other diseases increased at certain periods. It is a field of investigation most worthy of careful study. While some of the re-

ductions would perhaps have occurred had there been no change in the water supply, yet the evidence, on the whole, is so striking that it ought not to be ignored by those who have to deal with the relationship between sewage bacteria and the quality of public water supplies.

In comparing experiences with vital statistics at Cincinnati with those at Washington, Little Falls, and New Milford, it would be highly instructive to know what reductions in death rates for various diseases would have occurred if the Cincinnati water supply had been drawn from the new intake above the local sewers and the Little Miami river, without filtration.

Before seeing the later statistics from Cincinnati for the several causes of deaths above tabulated, the author was so impressed with the unusual decreases in some instances, that he wrote to the Health Officer, Dr. J. H. Landis, for his interpretation of them. The reply is so comprehensive as to the effect of improved methods of diagnosis and of other factors than water supply, that it is given in full, as follows:

STATEMENT OF DR. LANDIS.

Nothing has transpired here in Cincinnati to lead me to conclude that the mortality for other than hitherto recognized water-borne diseases has been affected by our change from raw to filtered water.

The mortality from diphtheria and croup owes its reduction, in my judgment, to the following factors:

1. Early use of antitoxin without waiting for a laboratory diagnosis.
2. More stringent quarantine regulations.
3. Medical school inspection.
4. A marked improvement in the milk supply and the sanitary conditions under which it is produced.
5. Holding all milk bottles at home of patient until quarantine is raised and then sterilization before returning to dairy.
6. Discharge of all diphtheria patients on negative culture tests through the Health Department.

Cancer of the stomach and liver are probably just as numerous as before filtration was installed.

I believe the improved methods of diagnosis can be credited for the apparent decrease in deaths from these causes.

"Convulsions" is no longer received in this office as a cause of death. They are a symptom—the death is credited to the disease producing them.

The prevalence of pneumonia depends largely upon the prevalence coincidentally of the infectious diseases—measles, whooping cough and influenza.

Education concerning the rôle played by foul air, dissipation, intemperance and irregular hours has doubtless helped to reduce the mortality from pneumonia.

"Stomach disease" is also unpopular as a cause of death in this office.

Diarrhea and enteritis, while influenced by the water supply, are more intimately affected by the quality of the milk supply and the amount of rainfall during the hot months.

Peritonitis is rarely accepted as a cause of death now. What caused the peritonitis? Charge it with the death.

In addition, surgery has done a great deal to reduce the number of cases developing. I believe it would be unfair to attribute the reduction to a change in the water.

The attack rate from acute nephritis may possibly be affected by the water supply, but I doubt very seriously any such influence.

Acute nephritis is almost invariably a complication. It would require a very thorough and painstaking analysis of the morbidity and mortality tables from other diseases before coming to any conclusion on this subject, and even then the conclusion might be far from convincing.

As a general proposition I believe there can be no doubt that the morbidity and mortality rates of a community from all diseases are affected to a degree by the character of the water supply.

That it is difficult to determine the degree one must admit. A polluted water need not necessarily produce typhoid, dysentery or cholera or bring on pneumonia, influenza, measles or scarlet fever, but it may so lower the vitality that people exposed to these infections are more liable to contract them and less able to withstand their ravages.

CLASSIFICATION OF CAUSES OF DEATH

Irregularities in this regard are to be carefully sought before drawing final conclusions from vital statistics. This point was well established by the litigation relative to the Chicago drainage canal. As stated by Prof. Jordan, the increase in recorded deaths from typhoid fever in St. Louis following the opening of the canal in 1900 was well defined. Yet if comparison were made of the sum of the reported deaths from typhoid fever and from remittent, intermittent, typho-malarial, congestive and simple continued fevers, no such inference would be apparent. Prof. Jordan concluded that the deaths from so-called malarial diseases were really due to typhoid, as stated on page 243 of

Water Supply and Irrigation Paper No. 194, U. S. Geological Survey. A list of causes of deaths as defined by a recent International Commission was published in book form in 1911 by the U. S. Census Bureau. It should prove of much aid to local registration offices.

THE WARREN EPIDEMIC OF GASTRO-ENTERITIS

The following account of the epidemic at Warren, Pa. (population about 10,000) is taken from the *Transactions of the American Society of Civil Engineers*, Vol. LIX, page 377, from the statements of Mr. F. Herbert Snow, Chief Engineer of the State Department of Health of Pennsylvania, who made an official inspection of the Warren situation.

At Warren, beginning on December 8, 1906, an epidemic of gastro-enteritis raged for four days, during which 1200 patients called for medical attention, and about 600 more were reported bedridden, but did not receive professional care.

This borough takes its water supply from driven wells, in the town, on the banks of the Alleghany River, the waters of which are polluted by sewage. Investigations by the Department of Health pointed conclusively to the water as the medium of transmission of the poison. From the nature of the ailment, it was premised that the infection must have been in concentrated form.

The cause was discovered to have been the sudden rising of the river and the back-flooding of sewage through a drain pipe and ultimately through loosened joints of the piping of the driven-well system and into the town's supply. Attention to the sewer, which was in a leaky condition, and to the joints and packing of the suction pipes, which joints and packing had been loosened by alterations in the main suction pipe, would have prevented trouble. Too much care cannot be exercised with respect to the condition of the apparatus by which ground-water is obtained for a public supply, when such apparatus is located on the banks of a sewage-polluted river in which freshet heights inundate the surface of the land upon which the wells are located. The danger exists if there be sewage in the river, or a conduit, or a receptacle, or anywhere whence it may be transmitted to the drinking water. The lesson taught by this experience is that a ground-water supply, regularly proven by tests to be of superior quality, may suddenly become contaminated from a known remote source, and be prejudicial to the public health. The remedy, therefore, if it be practicable to do so, is to remove the remote danger, in other words, to pay attention to the proper disposal of sewage.

The sewers of Warren discharge into the Alleghany river about 90 miles above the borough of Kittanning, in which the source of public supply is the same river. The water was filtered, and was supposed to be purified. However, expert investigation revealed the fact that the plant had not been operated intelligently, nor was it equipped to render satisfactory treatment of the water possible. Yet the public was led to believe that the system of purification as installed and operated was a sufficient safeguard.

Several days after the Warren outbreak a similar epidemic of gastro-enteritis broke out in Kittanning. It lasted more than 8 weeks and numbered in that time upward of 4000 cases. The physicians of the borough reported that the vast majority of citizens were afflicted and received medical attention

Pathogenic pollution from many municipalities on the banks of the river above Kittanning may arrive at the water-works intake at the latter place in condition capable of causing disease. The Warren infection might have been transmitted to Kittanning and have produced the epidemic there. The coincidence of outbreak in the two places attracts attention, although a local source of infection is more probable. But, besides the bowel trouble, there were more than 100 cases of typhoid fever in Kittanning. This infection is believed to have been introduced through the medium of the river.

This case demonstrates how utterly inefficient may be the effort of those who, misinformed as to the essentials of water filtration, try to safeguard human life. Here was a water purification plant, installed for the purpose of preventing a recurrence of typhoid fever, totally inadequate to perform the service expected of it by the public, but, nevertheless, serving to foster a false sense of security.

In such a case, where the source is always dangerous, the interests of the public health demand competent design and skilled supervision of the construction of the purification works at first, and thereafter capable management of its operation, and efficient maintenance.

THE LOWELL EPIDEMIC OF DIARRHEA

In the Massachusetts State Board of Health Report for 1903, page 605, is the following report of Dr. F. L. Morse, Medical Inspector of the Board, relating to a widespread epidemic of diarrhea which occurred at Lowell in August, 1903, after a serious fire which occurred in the previous month:

On August 1, the attention of the Board was directed to a large number of cases of diarrhea which had occurred at the Middlesex County jail, located in the city of Lowell. It was found that of a total of 92 people, 36 had had varying forms of severity of this disease, and it was further ascertained that upon July 18, a fire had occurred in the city,

and that accidentally a large amount of sewage-polluted Merrimac river water had gotten into the public water supply on the nights of July 18 and 19. Cases of diarrhea developed about July 23, and the disease was on the decrease at the time the visit was made. A proportionate number of cases of diarrhea was also present among the residents of the city.

Following this epidemic cases of typhoid fever appeared, the earlier ones going to bed on August 1, the number increasing and reaching its height on August 12, when 16 cases were reported as having gone to bed on that day. The number of cases diminished toward the latter part of the month, when it was found that there had been reported a total of 161 cases during the month. Cases continued to develop during September, when 39 were reported, October, when 17 were reported, and November, when 14 were reported.

The cause of this disease was evidently the accidental pollution of the public water supply. On the night of July 18 a fire occurred at the Merrimac mills, which necessitated the use of the city water in addition to the corporation supply in fighting the fire. The two supplies, although intended to be entirely separate, were connected at different parts of the city by a series of gates, each working automatically, which allowed the city's public water supply, obtained from driven wells, to flow into the corporation supply, but would not permit the Merrimac river water to flow back into the city supply. After the fire had been extinguished water was pumped from the wheel-pit of the Lawrence Manufacturing Company to fill the depleted corporation reservoir. After about nine hours of pumping, it was found that the reservoir was not proportionately filled, and investigation showed that one of the automatic gates had refused to work, and that a large amount of Merrimac river water, obtained at a point only a short distance below one of the large sewer outlets, had flowed into the city water pipes. Although this fact was known to the Water Board of the city, no warning was given to the residents, and, consequently, they drank the water, expecting no evil results. On the 30th of July, after the epidemic of diarrhea had subsided, the water pipes were flushed to remove whatever small amount of polluted river water might be left in them; but a bacteriological examination made on the 29th and 31st of the month still showed the presence of colon bacilli in the water. Of these cases, 10 proved fatal, and the ill effects of the introduction of the polluted river water for a few hours only was evident during the succeeding four months.

THE LINCOLN EPIDEMIC OF DIARRHEA AND TYPHOID FEVER

The city of Lincoln, Nebr. has a population of about 45,000 people. It is supplied with water from several deep masonry

wells of which one, the Rice well, furnishes perhaps 25 to 30 per cent. of the total volume of water which is sent directly into the pipe system without any storage reservoir for the pressure water. On Dec. 13 to 16, 1911, there developed an extensive epidemic of diarrhea; in fact, it appeared in practically every household in that portion of Lincoln that received water from the Rice well. An epidemic of typhoid fever later appeared in the same district. This proposition was investigated by Mr. James C. Harding who found that the records of the extent of the diarrhea epidemic were meager, but that it probably involved some 3000 or more cases. There were about 300 cases of typhoid fever between Dec. 20, 1911, and Jan. 15, 1912. The height of this epidemic was about Jan. 1, 1912, or about 16 days after the diarrhea epidemic was at its height.

Upon investigation Mr. Harding found that the cause of these epidemics was the sewage pollution of the well water, caused by the accidental stopping up of a nearby sewer, resulting in leakage to an abnormal extent through joints in the sewer pipe which had settled. As in the cases at Lowell, Mass. and Warren, Pa., it is thus seen that a small quantity of sewage may do much mischief and is likely to assert itself within a few hours in a widespread epidemic of diarrhea, followed some two weeks or more later by an outbreak of typhoid fever. The details as to such epidemics naturally depend to a considerable extent upon the nature of the infection in the sewage-polluted ground waters.

An article describing the Lincoln epidemic is given in *Municipal Journal and Engineer* of Feb. 22, 1912, page 280.

LONGEVITY OF TYPHOID BACILLI IN WATER

For twenty-five years much study has been given by bacteriologists to the longevity of typhoid fever and other disease germs in water. Literature abounds with various references to their behavior. Some say they multiply rapidly and others say they die out very quickly. In natural waters, that is, those which have not been sterilized and treated in the laboratory, there is no doubt that ordinarily the typhoid germ not only does not multiply, but that it gradually dies. It may be that there are some conditions in nature whereby typhoid fever might multiply in water, but if such is the case there are no well-authenticated data known to the author in support of it.

Some twenty years ago or more, during the earlier studies of the severe typhoid epidemics in cities of the Merrimac river valley, the staff of the Massachusetts State Board of Health devoted much time to studying the life history of typhoid fever germs in various samples of the Merrimac river water. The conclusions were stated by Mr. Mills on page 542, of the 1890 Report of the Massachusets State Board of Health, as follows:

To prove whether typhoid-fever germs would survive in the Merrimac river water, when at the low temperature of the month of November, long enough to pass from the Lowell sewers to the service-pipes in Lawrence, a series of experiments was made by the Board by inoculating water from the service-pipes with typhoid-fever germs, and keeping the water in a bottle surrounded by ice, at as near freezing as practicable, for a month and each day taking out 1 cubic centimeter and determining the number of typhoid germs. The number continually decreased, but some survived 24 days.

On the first day there were	6120 germs
On the fifth day there were	3100 germs
On the tenth day there were	490 germs
On the fifteenth day there were	100 germs
On the twentieth day there were	17 germs
On the twenty-fifth day there were	0 germs

Mr. Geoge C. Whipple, in his comprehensive book on "Typhoid Fever," reviews the life history of typhoid-fever germs very carefully. Among his statements is a description of the diagram which he prepared, based upon data available in 1903, when this matter received so much attention in connection with the litigation over the Chicago drainage canal. The chart given by Mr. Whipple indicates the range of variation in the rate at which bacterial cells die. This is no doubt due, in part, to the vitality of the germs themselves, in part to the temperature of the water, in part to the organic matter, and in part to bacterial antagonism from other contents of the water in which typhoid germs are placed.

Generally speaking, it may be said that about 50 per cent. of the bacteria will die in from one to four days and about 90 per cent. of bacteria will die in from three to thirteen days. A few of the most hardy cells continue to live for weeks and probably months, and constitute what Mr. Whipple calls the "resistant minority." Whether the germs of unusual resistance and

longevity are more virulent or less virulent than normal is something about which practically nothing is known specifically.

In sewage typhoid bacilli seem to die measurably more quickly than in fairly pure water. In all natural waters the amount of organic matter present is such as to eliminate the quantity of food as a factor of importance. Their death in sewage is probably explained by the antagonism of other kinds of bacteria, perhaps by the influence of enzymes or toxins produced by other kinds of bacteria. Another factor of importance is the absence of oxygen, which experiments indicate to be necessary for longevity according to Mr. Whipple.

By far the most important investigations which have been made of the longevity of the typhoid fever germ in waters of different character were those made by Messrs. Jordan, Russell and Zeit, for the Chicago Sanitary District in connection with the litigation over the Chicago drainage canal. Their conclusions point to a shorter duration of life than had generally been considered hitherto, especially in sewage as compared with lake water. The wide familiarity of Prof. Jordan with the literature of this subject prompts a citation of his summary of the distribution of typhoid bacillus in nature, as stated in his text-book on "Bacteriology," edition of August, 1910, page 273, as follows:

> The typhoid bacillus is by preference a parasite. Outside the human body it has been found only in those situations where it could be more or less directly traced to an origin in the discharges of a typhoid patient or convalescent. Many of the earlier reported findings of this organism in water and soil cannot now be given credence, owing to the inadequacy of the identification tests to which the cultures were subjected. Up to the present time relatively few well-authenticated instances have been recorded in which the typhoid bacillus has been found in water, soil, and similar situations. Laboratory experiments have shown that the typhoid bacillus can survive in sterile water in glass vessels for upward of three months, and for possibly two or three weeks in unsterilized ground or surface water. Other evidence indicates that the bacillus is able to travel in water a distance of at least 140 kilometers and to retain its vitality in natural bodies of water for at least four or five days (Jordan, Russell and Zeit).[1] It is possible that water may continue to be the vehicle of infection during a much longer period, but the available data point to a comparatively short duration of life of the specific germ in the water of flowing streams (Jordan, Russell and Zeit). Under ordinary conditions no multiplication of the typhoid bacillus takes place in

[1] Jordan, Russell and Zeit: *Journal of Infectious Diseases* 1904, I, page 641.

water, even when a considerable amount of organic matter is present, but, on the contrary, a steady decline in numbers goes on. The history of typhoid epidemics tends to show that sewage pollution is to be feared chiefly when the sewage is fresh, and that the danger of infection diminishes progressively with the lapse of time.

In soil and in the fecal matter of privy vaults, the duration of life of the typhoid bacillus is much longer than in water. Levy and Kayser[1] found typhoid bacilli in soil that had been manured fourteen days previously with the five-months-old contents of a vault. The evidence that any genuine multiplication can take place in the soil is not convincing, but it has been proved that the bacillus may be carried by water currents to a considerable distance from the point where it was first introduced. Infection of wells and small watercourses is thus brought about sometimes by the washing of bacilli out of soil in which they may have lain dormant for many months. The persistence of typhoid fever around certain habitations may be plausibly explained on the supposition of an extensive soil infection. There is no doubt that the practice of using human excrement for manuring vegetable gardens entails a danger no less real because often unrecognized.

The history of typhoid epidemics indicates that air-borne infection is, to say the least, exceedingly rare. Sewer air, so far as known, is never the vehicle by which the specific germ of typhoid fever is conveyed from one place to another.

RÉSUMÉ

Sewage bacteria include at times the germs of typhoid fever, Asiatic cholera, and diarrhea. These diseases are abnormally prevalent in communities receiving in an unpurified condition a water supply that is sewage polluted.

Where a water supply as delivered to consumers is grossly polluted with sewage, the general death rate is likely to be abnormally high and to an extent greater than can be accounted for by the diseases above mentioned. Why this is so is not definitely known. With moderately or slightly polluted water supplies the influence of sewage bacteria is apparently not always a well defined factor in the general death rate except insofar as it relates to the well-known water-borne diseases above mentioned as they may show themselves from time to time.

There is no room for doubt about a little sewage creating much mischief if it enters a water supply only for a few hours at rare intervals. It is a serious menace to the public health. Sewage

[1] Levy and Kayser: *Centralbl. f. Bakt.*, 1903, XXXIII, page 489.

bacteria should not be delivered to water consumers. They should either be prevented from entering the water supply if that is practicable, or if such prevention is impracticable they should be removed by efficient filtration or sterilization or both.

There are other means of transmitting water-borne diseases than by the public water supplies. This is well shown by the variations in death rates of neighboring cities which receive the same public water supply.

Efficient sanitary laws rigidly enforced, personal hygiene and reliable diagnosis and classification of deaths are all factors of great importance in the study of vital statistics as related to sewage bacteria.

Typhoid bacteria die quite rapidly in ordinary waters and so far as known never multiply in natural waters. In a few days a majority of the germs will die and in a week or two much more than 90 per cent. will ordinarily have disappeared. A small number of resistant typhoid fever germs will live, however, for weeks, months and perhaps years. The germs of Asiatic cholera seem to behave in a manner quite similar to those of typhoid fever, although our information about them is less definite.

CHAPTER V

SEWAGE BACTERIA AS RELATED TO SHELLFISH

Oyster scares during the past 15 years or so have been of sufficiently frequent occurrence to produce considerable agitation in the mind of the public. They have resulted in such a feeling of uncertainty that it has affected somewhat the shellfish industry, causing the dealers who handle shellfish from sources above suspicion to suffer from the faults of their competitors. In brief, the marketing of shellfish in some places from sewage-polluted waters has produced a condition of affairs which needs correction in a practical way, both from the standpoint of the public health and of the shellfish industry.

Several years ago the author had occasion to examine carefully the available literature concerning the transmission of typhoid fever by oysters and other shellfish. This information, with a fairly complete bibliography, was embodied in a paper read before the Franklin Institute in June, 1905. Free use is made of the material of that paper in the following pages, to serve as an introduction to the official action taken recently by the U. S. Board of Food and Drug Inspection and several state authorities in the interest of the public health.

While typhoid fever is the disease most discussed in this connection, it seems fair to say, reasoning from analogy, that cholera, diarrhea, gastro-enteritis and other diseases spoken of in Chapter IV are entitled to consideration in studying exhaustively the effect of sewage bacteria upon shellfish. The details of this proposition will not be entered into here, as it is considered sufficient merely to record the practical importance of such aspects of the matter.

The principal oyster in America, Ostrea Virginiana, is found along the Atlantic coast, from Maine to Texas. The extent of the oyster and clam industry and an approximate idea as to its relative distribution along the coast is shown in Table 34. These statistics for the year 1908 are copied from page 42 of the *Special Report of the U. S. Census Bureau, Department of Commerce and Labor*, dated July 27, 1911.

The so-called "Little Neck" clam, or small round clam, in most general use is here classified as the "hard" clam, or what is commonly known in New England as the "quahog."

TABLE 34.—PRODUCTS. DETAIL SUMMARY BY STATES AND BY SPECIES: 1908

Species and state	Quantity (pounds)	Value
Clams, hard		
United States	7,805,000	$1,317,000
California	132,000	4,500
Connecticut	100,000	20,000
Delaware	6,900	1,300
Florida	239,000	15,000
Georgia	43,000	9,400
Louisiana	100	(1)
Maryland	82,000	16,000
Massachusetts	1,119,000	189,000
New Jersey	2,184,000	318,000
New York	809,000	223,000
North Carolina	726,000	82,000
Oregon	700	100
Rhode Island	162,000	39,000
South Carolina	76,000	6,300
Virginia	1,969,000	380,000
Washington	155,000	13,000
Clams, soft		
United States	8,654,000	553,000
California	468,000	5,300
Connecticut	42,000	5,500
Maine	5,061,000	251,000
Massachusetts	1,916,000	186,000
New Jersey	205,000	11,000
New York	656,000	54,000
Oregon	30,000	2,000
Rhode Island	275,000	38,000
Clams, razor		
United States	259,000	25,000
Massachusetts	24,000	3,600
Washington	234,000	22,000
Clams, surf		
United States	265,000	$21,000
New Jersey	99,000	7,000
New York	167,000	14,000

(1) Less than $100.

TABLE 34.—PRODUCTS. DETAIL SUMMARY BY STATES AND BY SPECIES: 1908—(*Continued*)

Species and state	Quantity (pounds)	Value
Oysters		
United States	233,309,000	15,713,000
Market	178,293,000	12,721,000
From public areas	103,641,000	4,416,000
From private areas	74,652,000	8,305,000
Seed	55,016,000	2,992,000
From public areas	26,960,000	1,035,000
From private areas	28,056,000	1,957,000
Alabama	4,132,000	173,000
Market	3,754,000	169,000
From public areas	3,314,000	132,000
From private areas	440,000	37,000
Seed, from public areas	378,000	4,100
California, market, from private areas	729,000	337,000
Connecticut	27,636,000	2,583,000
Market	9,762,000	1,168,000
From public areas	44,000	4,400
From private areas	9,718,000	1,163,000
Seed	17,874,000	1,415,000
From public areas	1,478,000	99,000
From private areas	16,396,000	1,317,000
Delaware	2,434,000	169,000
Market	1,082,000	112,000
From public areas	177,000	10,000
From private areas	905,000	102,000
Seed	1,352,000	57,000
From public areas	1,303,000	53,000
From private areas	49,000	3,500
Florida, market	7,467,000	296,000
From public areas	7,327,000	284,000
From private areas	141,000	12,000
Georgia	10,214,000	$339,000
Market	10,053,000	334,000
From public areas	3,484,000	121,000
From private areas	6,569,000	213,000
Seed	161,000	4,600
From public areas	63,000	1,800
From private areas	98,000	2,800
Louisiana	25,553,000	763,000
Market	20,762,000	675,000
From public areas	13,363,000	341,000
From private areas	7,399,000	334,000
Seed	4,791,000	88,000
From public areas	4,091,000	82,000
From private areas	700,000	6,200

TABLE 34.—PRODUCTS. DETAIL SUMMARY BY STATES AND BY SPECIES: 1908—(*Continued*)

Species and state	Quantity (pounds)	Value
Oysters (con.)		
Maine, market, from public areas	1,000	200
Maryland	43,624,000	2,228,000
Market	40,811,000	2,127,000
From public areas	39,718,000	2,041,000
From private areas	1,094,000	86,000
Seed, from public areas	2,812,000	101,000
Massachusetts	1,084,000	218,000
Market	868,000	203,000
From public areas	4,900	900
From private areas	863,000	202,000
Seed	216,000	15,000
From public areas	43,000	3,100
From private areas	173,000	12,000
Mississippi, market	7,473,000	295,000
From public areas	7,423,000	292,000
From private areas	50,000	3,800
New Jersey	18,105,000	1,369,000
Market	6,437,000	884,000
From public areas	107,000	12,000
From private areas	6,330,000	872,000
Seed	11,668,000	485,000
From public areas	5,402,000	236,000
From private areas	6,266,000	248,000
New York	17,244,000	2,553,000
Market	12,946,000	2,173,000
From public areas	151,000	18,000
From private areas	12,795,000	2,155,000
Seed	4,298,000	381,000
From public areas	628,000	45,000
From private areas	3,670,000	336,000
North Carolina	5,690,000	$236,000
Market	5,275,000	227,000
From public areas	5,209,000	220,000
From private areas	66,000	7,300
Seed	415,000	8,800
From public areas	401,000	8,500
From private areas	14,000	300
Oregon	9,100	4,200
Market	7,300	4,000
From public areas	2,300	800
From private areas	5,000	3,200
Seed, from public areas	1,800	200
Pennsylvania	1,938,000	176,000
Market, from private areas	906,000	134,000
Seed, from public areas	1,032,000	42,000

TABLE 34.—PRODUCTS. DETAIL SUMMARY BY STATES AND BY SPECIES: 1908—(*Concluded*)

Species and state	Quantity (pounds)	Value
Oysters (con.)		
Rhode Island	8,602,000	969,000
Market, from private areas	8,564,000	967,000
Seed	38,000	2,500
From public areas	21,000	1,500
From private areas	18,000	1,000
South Carolina, market	10,942,000	137,000
From public areas	10,331,000	129,000
From private areas	610,000	8,000
Texas	3,481,000	168,000
Market	3,428,000	167,000
From public areas	3,404,000	166,000
From private areas	24,000	1,200
Seed, from public areas	52,000	600
Virginia	35,525,000	2,348,000
Market	25,705,000	1,967,000
From public areas	9,581,000	645,000
From private areas	16,124,000	1,322,000
Seed	9,820,000	381,000
From public areas	9,252,000	357,000
From private areas	568,000	24,000
Washington	1,425,000	352,000
Market, from private areas	1,321,000	346,000
Seed, from private areas	104,000	6,500

TABLE 35.—SUMMARY BY COUNTRIES

Country	Oysters	
	Bushels	Value
United States	28,138,434	$14,313,753
Great Britain	2,760,000	6,200,000
France	2,000,000	5,000,000
Canada	152,580	183,846
Holland	70,000	444,000
Italy	65,000	200,000
Germany	13,000	75,000
Other countries	400,000	600,000
	33,599,014	$27,016,599

A general idea of the extent of the oyster industry throughout the world is shown in Table 35, the annual statistics of which it is to be stated are not strictly comparable, as they refer in various instances to different years beginning about 1890 and extending down to 1904. They are sufficient, however, for present pur-

TABLE 36

Rank	Species	Fishery Products: 1908			
		Quantity		Value	
		Pounds	Per cent. distribution	Amount	Per cent. distribution
	Total	1,893,454,000	100	$54,031,000	100
1	Oysters	233,309,000	12	15,713,000	29
2	Salmon	90,417,000	5	3,347,000	6
3	Cod	110,054,000	6	2,914,000	5
4	Shad	27,641,000	1	2,113,000	4
5	Lobster	15,279,000	1	1,931,000	4
6	Clams[1]	16,717,000	1	1,896,000	4
7	Squeteague	49,869,000	3	1,776,000	3
8	Halibut	34,441,000	2	1,562,000	3
9	Haddock	59,987,000	3	1,308,000	2
10	Carp, German	42,763,000	2	1,135,000	2
11	Lake herring	41,118,000	2	989,000	2
12	Crabs[2]	52,913,000	3	912,000	2
13	Mullet	33,703,000	2	908,000	2
14	Menhaden	394,776,000	21	893,000	2
15	Mackerel	12,103,000	1	848,000	2
16	Lake trout	12,024,000	1	800,000	1
17	Herring, salt-water	125,050,000	7	796,000	1
18	Catfish	17,817,000	1	785,000	1
19	Mussel shells, pearls, and slugs	81,869,000	4	692,000	1
20	Snapper	13,854,000	1	651,000	1
21	Alewives	89,978,000	5	589,000	1
22	Flounders	23,346,000	1	588,000	1
23	Pike perch	15,247,000	1	580,000	1
24	Sponges	622,000	*	545,000	1
25	Whitefish	7,722,000	*	524,000	1
26	Bluefish	7,647,000	*	506,000	1
27	Buffalo fish	16,729,000	1	498,000	1
28	Shrimp and prawn	19,080,000	1	494,000	1
29	Hake	34,340,000	2	464,000	1
30	Pollock	29,462,000	2	402,000	1
	All other	183,574,000	10	6,872,000	13

[1] Not including surf clams.
[2] Not including king, spider, and stone crabs.
* Less than 1 per cent.

poses in conveying a general impression as to the relative extent of this important industry.

The value of the annual output of oysters, clams and other mollusks amounted in 1908 in the United States to about one-third of the total value of all fishery products, as shown in Table 36, copied from page 24 of the Census Report of July 27, 1911:

EARLY INSTANCES OF DISEASE TRANSMISSION THROUGH INFECTED OYSTERS

Even prior to the establishment of the germ theory of disease some 25 or 30 years ago, numerous cases were cited of the well-established relationship between typhoid fever, cholera and similar intestinal diseases and oysters polluted with human excreta.

The first instance on record was cited by Dr. Pasquier in 1816. This French physician wrote a book entitled "The Oyster from the Medical Point of View," and in it described an instance where a workman laid down 60,000 oysters in a fattening bed excavated in the moat of an old citadel into which the sewage of the garrison had been discharged for centuries. These oysters were consumed for the first time on Sept. 10, 1816, and on the 20th and 21st of the same month, after the lapse of the necessary period of incubation for typhoid fever germs, cases of that disease made their appearance among the consumers.

In 1820 the British medical journals recorded an outbreak of gastro-enteritis at Dunkirk, which was reported to have been due to oysters procured on the coast of Normandy.

During the cholera epidemic in Great Britain in 1849 an outbreak of this disease occurred at Bridgewater and Taunton, which was considered to have been due to the consumption of some apparently decomposing oysters which had been condemned as unfit for food, but which were, nevertheless, given to school children in the district. This outbreak was officially examined by Dr. Britton of the General Board of Health, and was referred to a little later in medical literature by Sir D. W. Richardson.

In 1876, on the Isle of Man, there occurred an epidemic of typhoid fever which was alleged to have been due to the consumption of oysters.

The earliest reference in more recent medical literature to this subject occurs in a paper read before the British Medical Associa-

tion in 1880 by Sir Charles Cameron, Health Officer of Dublin, Ireland. His proposition that oysters obtained from polluted sources might cause typhoid fever was so novel that the chairman of the meeting inquired if his paper were intended as a joke. In 1889 it appears from the investigations of this gentleman that cases of typhoid fever in Dublin were recorded as possibly having had their origin in oysters which had been laid down in the sewage-polluted Dublin bay.

Prof. de Giaxa, of Pisa, made a study of the bacterial flora of the bay of Naples, and in his paper in 1889 recorded some observations on the longevity of the disease germs in salt water, and referred then and later to the question of infection by shellfish.

Following the epidemic of cholera in Hamburg late in 1892, there appeared some scattered cases of cholera in England, which were considered to have been directly caused in part by the consumption of oysters from Cleethorpes and Grimsby, according to Sir R. Thorne, medical health officer of the local government board, and Dr. Reece, inspector.

RECENT OUTBREAKS OF TYPHOID FEVER DUE TO INFECTED OYSTERS AND OTHER SHELLFISH

The epidemic of typhoid fever associated with polluted shellfish which has attracted most widespread attention was that at Wesleyan University, at Middletown, Connecticut. As stated in the admirable report of Prof. Conn, there were seven fraternity banquets on October 12, 1894, at Middletown, which were attended by about 100 students, some of whom were guests from other universities. Following the ordinary period of incubation of typhoid fever, twenty-three cases of this disease appeared among the local students and six cases among the guests who had attended three of these banquets. By a most exhaustive inquiry there were eliminated other foods which might possibly have conveyed typhoid fever germs, including water, ice, milk, ice-cream, uncooked vegetables, etc. By eliminating these articles of food and drink and by comparing the portions of the menu eaten by those who did and those who did not sicken of typhoid fever, and, further, by comparing the diet before and after the banquet of the various students and guests, there was left no room for doubt about the uncooked oysters being the source of infection. Ad-

ditional weight was given to this conclusion by the appearance of typhoid fever among six of the guests who had eaten oysters at these banquets, but who had not been exposed to any local factors other than at the banquet, and by the further fact that no typhoid fever appeared among students attending on the same evening the other four banquets, at which oysters were served, either from other sources or cooked.

Investigation showed that the oysters in question had been obtained from Fairhaven, Conn. They had been taken from deep water in Long Island Sound and brought into the mouth of the Quinnipiac river and allowed to lie in brackish water for a day or two for fattening. Close to the fattening beds were the outlets of a number of private sewers, one of which, 300 feet distant from the bed, drained a house in which were two cases of typhoid fever. Each link in the chain of evidence was established beyond all reasonable doubt.

It was the Middletown epidemic which first drew the attention of the public in a prominent way to the relation between shellfish and diseases. Since that time many instances have occurred of somewhat similar nature.

Among those which were investigated most carefully by competent official sanitarians may be mentioned the mayoralty banquets, in 1902, at Winchester and Southampton, England. In this instance there were two banquets, held on the same evening in distant cities, at which oysters from the same polluted source were served uncooked. At each banquet a considerable portion of the guests were shortly seized with gastro-enteritis, and others were later attacked with typhoid fever. Of 267 guests, 118 suffered from the former and 21 from the latter disease.

Instances of such outbreaks are a matter of record in nearly all countries where oysters or other shellfish are eaten in an uncooked condition. It is needless here to recite them all in detail, the particulars of which can be largely ascertained in Dr. H. T. Bulstrode's testimony before the Royal Commission, and his classical paper on "Oyster Culture in Relation to Disease," issued by the Local Government Board of England in 1896. As a matter of convenient record, however, reference may be made here to a few of the more important ones, as follows:

Truro, England.—A supper party of seven in this city was reported to have eaten oysters from a source known to be polluted. All of them were taken ill, some with typhoid fever

and some with gastro-enteritis. The medical officer of health of the city, Dr. Sharp, reported in 1897 that the infected oysters were the cause.

St. Andre de Sangonis, France.—Dr. Chantemesse read a paper on this subject before the Paris Academy of Medicine. He drew attention to fourteen persons from six families having eaten raw oysters taken from the sewage-polluted canal at Cette. All of these persons were made ill, some with typhoid fever and some with gastro-enteritis, while no illness whatever appeared among the members of these families who ate no oysters.

Dr. Mosny, who wrote an excellent series of articles some years ago on "Mollusk Poisoning" in France, refers to a more recent instance in a village near Paris, where gastro-enteritis followed the eating of oysters from Cette.

Other instances of oyster pollution are reported from Monte Carlo, Naples, Florence, Milan, Constantinople and New Zealand. Numerous physicians could doubtless recite cases of shellfish infection within their observation, typical instances of which were recorded by Sir William Broadbent in 1895.

Clams, mussels and other shellfish have been found to transmit disease, but as they are not so generally in use as oysters (at least in America), the well-known cases are not so numerous as with the oysters.

Patrons of summer resorts, especially at the seashore, doubtless suffer more from infected shellfish, as a general proposition, than is believed by many. To trace clearly the significance of such factors in a floating population is obviously difficult. It is of interest, however, to mention instances at Atlantic City and at Lawrence, L. I.

Atlantic City, N. J.—This well-known seashore resort, although provided with a public water supply of satisfactory quality, and with a milk supply found upon careful examination to have been safe, has at times suffered from an undue prevalence of typhoid fever, especially during the summer of 1902. The cause of this typhoid fever was found to be largely due to oysters freshened in sewage-polluted waters, and clams taken from similar waters, according to an investigation made by the Atlantic City Academy of Medicine. This conclusion was concurred in by Prof. A. C. Abbott and Prof. Henry Leffman, of Philadelphia. Since the taking of shellfish from polluted sources has been prohibited by the local board of health there has been no abnormal prevalence

of typhoid fever at this resort, according to Dr. Guion, health officer.

Lawrence, L. I.—This small summer resort on the Rockaway peninsula on the south shore of Long Island suffered during the summer and autumn of 1904 from a sporadic outbreak of typhoid fever, the total number of cases being 31. According to the careful investigations of Dr. Soper, more than two-thirds of these cases were traced directly or indirectly to shellfish taken from the adjoining coves of Jamaica bay, the water of which is polluted with local sewage.

RELATION OF POLLUTED SHELLFISH TO THE GENERAL PREVALENCE OF TYPHOID FEVER

A moment's reflection will show that the most serious aspect of oyster pollution does not relate by any means to outbreaks at large banquets or summer hotels, but rather to the significance which this proposition bears to the various cases of this disease scattered throughout the entire world of shellfish-eating people. It is well known that typhoid fever frequently appears among people who, so far as can be ascertained, have not been exposed to infected water, milk or other foods. These occurrences constitute what are generally called sporadic or isolated cases of typhoid fever.

To ascertain even in a general way the relation of various shellfish to these isolated cases is a very difficult and complicated matter. In the recent inquiry conducted in a most careful manner into this general proposition by the Royal Commission of Great Britain on the disposal of sewage, a circular letter requesting information upon this subject to thirty-one county councils drew forth the fact that twenty-one of them had no evidence bearing upon the question. The principal information elicited by these letters from the remainder may be briefly summarized as follows:

Southend-On-Sea, England.—The health officer, Dr. Nash, expressed his opinion, as the result of careful investigation, that at least 50 per cent. of the local typhoid fever cases were due to the consumption of shellfish from sources contaminated by sewage.

Yarmouth, England.—Dr. Nash also quoted typhoid fever statistics from Yarmouth, where this disease had prevailed to a

high degree for several years prior to 1900, when the sale of mussels from the River Yare was stopped. In 1901 the typhoid fever records showed only about 30 per cent. of the previous average, and in 1902 there was still further reduction.

Brighton, England.—During the years 1894 to 1902 the health officer, Dr. Newsholme, investigated each case of typhoid fever in Brighton and found that out of a total of 643 cases, 158 were directly ascribable to the consumption of oysters and eighty other cases to the consumption of other shellfish within the period of incubation. These shellfish in each instance were taken from layings proven to be exposed to sewage pollution. In the opinion of Dr. Newsholme, 37 per cent. of all typhoid fever cases is an under estimate of the effect upon that community of polluted shellfish.

Manchester, England.—During the years 1897 to 1902, inclusive, 2664 cases of typhoid fever occurred, and according to the health officer, Dr. Niven, 118 of these were strictly ascribable to oysters and mussels, and 156 more were associated with the consumption of other shellfish. In round numbers, therefore, in the city of Manchester about 10 per cent. of the typhoid fever during this period seems to have been due to polluted shellfish.

London, England.—According to Health Officer Murphy, of the Metropolitan District of London, more than 8 per cent. of all the cases of typhoid fever in that district during 1902 were indicated by consistent evidence to have been caused by polluted shellfish.

In America the evidence obtained as to the relation between typhoid and shellfish has not been exhaustively studied. It has received considerable attention in New York City, where in a bulletin dated Dec. 7, 1911, Health Commissioner Lederle states that diligent investigation has failed to trace any cases of typhoid fever for several years to the eating of oysters. At New Bedford, Mass., this has not been the case at all times, as stated in the chapter on Dilution in Tidal Waters. There are no adequate data on which to base any comparisons with the experiences in the English cities above cited. When the much-needed data upon this question are available, it will probably be found that the wider use of shellfish in America than in Europe will be a factor; although, of course, the net result depends upon the number of infected oysters reaching a given population.

CONCERNING THE LIFE HISTORY OF THE OYSTER

It is not the intention here to enter into a detailed technical description of the anatomy or physiology of the oyster. It is desired, however, to refer somewhat briefly to those well-known features of its mode of living which bear a relation to possible opportunities for the oyster to become polluted in waters containing sewage or other undesirable drainage.

Larval Oysters.—Like all other mollusks, the oyster reproduces exclusively by eggs. Each spatting oyster is estimated to give rise to more than 1,000,000 ova in a single season. From the eggs there are hatched small free-swimming larvæ, which swim with the tide, current or wind, and are carried frequently far away from their native bed. A large proportion of them, however, never reach maturity. Not only are the larvæ destroyed by cold and by living enemies in the water, but many of them perish by becoming deposited in muddy places where survival is impossible. After the larvæ pass through the free-swimming stage, those which develop further become fixed upon some hard, clean substance.

Oyster Spats.—When the shell of the infant oyster becomes large enough to cause deposition it is commonly called, at this stage of development, the "oyster spat." It has the appearance of a white glistening speck, not unlike a spot of candle grease. The spatting season varies in different localities, but ordinarily occurs within the period from May to September, inclusive. The oyster farmer gives careful attention to the "fall of spat," and in many instances artificial collectors are provided, upon which they may become deposited. These frequently consist of clean, empty oyster shells, branches of trees, tiles, etc. In the natural beds the spats become attached to rocks or reefs; if they do not reach some solid support, they obviously sink in the mud and become smothered. Care is required to keep the beds in good condition, as to freedom from weeds, deposits and antagonistic kinds of life.

Seed Oysters.—The seed oyster is one which has grown sufficiently upon artificial collectors until it has reached perhaps one year of age or so, when it is frequently removed to other beds. It is said that about 40 per cent. of the oysters in the United States are obtained from natural beds, and the remainder are transplanted to places where the oyster does not breed or grow to advantage. Probably the most important factor of all is

the fact that the natural beds cannot supply the demand. For some time oyster transplanting has been an industry carried out on a large scale in this country, and is now receiving much careful attention. The future will doubtless see still further attention to oyster culture.

Food Supply.—The oyster lives upon the various suspended matters contained in sea water, about 90 per cent. of the food being diatoms, or low forms of plant life, which are capable of growing on the mineral contents of sea water. This suspended matter reaches the stomach of the oyster, after having been filtered out from the water which passes through the gills. This process is well described by Prof. Brooks, of Johns Hopkins University, as follows:

> Every oyster in the bay is engaged day after day throughout the year, all day and nearly all night, in drawing into its shell a stream of water, filtering this through its gills, and then discharging this stream of water again. This stream can be traced for 5 or 6 feet away from the oyster by the disturbance it produces in the water. In fact, I think it is hardly an exaggeration to say that every drop of water that enters the Chesapeake bay from the Susquehanna river has a good chance to be filtered through the gills of an oyster before it reaches the ocean. After the oyster draws this stream of water into its shell, the water passes through microscopic pores over the surface of the gills, and out again through the vent pipe. During this process all microscopic organic life, or most of it, is filtered out. This is so true that those who manage aquaria have long been aware that water which has been filtered by the fresh-water mussel is peculiarly adapted to their uses, because it does not contain the germs of the green algæ which grows so profusely upon the sides of glass vessels, this material being so perfectly taken out by the mussel that the glass remains clean for a long time. The oyster does the same thing. These organisms, instead of going through the pores of the gills with the water, are entangled in the cement which the gland cells of the gills are continuously pouring out, and they are pushed along until they reach the mouth of the oyster, and are passed along into the stomach, where they are ultimately digested and converted into the wholesome substance of the oyster.

Bloating and Bleaching of Oysters.—In all countries, one of the characteristic features of the oyster industry is the frequent, though not universal, custom of removing the oysters with rakes or dredges, after they have grown to be of a sufficient size, from the oyster beds proper, and their placement for a day or more in drinking-houses, or floats. The latter are located ordinarily in coves or bays, or in the mouth of fresh-water streams, where the

water is brackish. An object of this is to bloat, bleach or freshen the oysters. This is accomplished by the oysters drinking a comparatively large quantity of the brackish or fresh water, thereby, on account of difference in the specific gravity, causing them to become bloated,with the salty flavor, due to sea water, largely removed, and also giving them a much lighter color, due to being filled with fresh water. (See tentative order of the Federal Board of Food and Drug Inspection, issued on Dec. 22, 1911, as given on page 156.)

Fattening of Oysters.—The above-mentioned bloating process, which the oystermen say increases the market value of the product, but which is seriously objected to by many devotees of fine oysters, is not to be confused with fattening, which, in a limited way, is done by transplanting to shallow bodies of salt water, where the diatomaceous food is more abundant than around the natural beds. The latter process is an important branch of artificial oyster culture, which has long received attention in France and elsewhere.

Opportunities for Pollution.—Enough has been said above to make it plain that the oyster, even in natural beds, may at times be found in a water which is dangerously polluted with sewage, and that particularly dangerous pollution may be afforded by the custom of bloating the oysters by removing them just prior to their being marketed to special layings along shore. It is also apparent from what is said above that if disease germs are contained in the water in which the oysters are placed, there is a strong likelihood of these germs being filtered out by the oyster as the water passes through its gills and enters the body of the oyster.

We will now trace the available evidence as to the significance of disease germs entering the oyster body.

CONCERNING THE DETECTION OF TYPHOID FEVER GERMS IN OYSTERS AND IN WATER

In the present state of the art, bacteriology does not afford ready and reliable means for the detection and isolation of the bacillus of typhoid fever in water, or in shellfish when present in such numbers as ordinarily exist in nature. With difficulty the numbers present may be roughly approximated only in the laboratory when those present are excessively numerous due to artificial infection of the oyster or the water.

Accordingly, in the absence of direct means of studying the

distribution of this germ in oysters and associated waters, it becomes necessary to study the problem indirectly. Along the latter line there are several ways of approaching the subject, viz.:

(a) Evidence as to the longevity of the typhoid germs in sea water. This evidence is, of course, considered in connection with the time interval required for the passage of sewage from local outfalls to oyster beds in the vicinity.

(b) Topographical and physical evidence, such as distances, depths, volumes, tides, currents, etc., for studying each local problem as indicated in the foregoing paragraph.

(c) Comparison of the numbers of bacteria and organic contents of the water from above the oyster beds with that of sea water from unpolluted sources, paying special attention to the relative numbers of bacillus coli, which is the most prevalent species of bacteria in the intestines of man and other warm-blooded animals.

(d) Comparison of the bacillus coli contents of oysters (including the body, liquid and shells) from unpolluted sources with those from the locality in question.

(e) Evidence, so far as present methods of bacteriology permit, as to the behavior and duration of life of typhoid fever germs within and upon oysters which have been infected with this germ.

LIFE OF TYPHOID FEVER GERMS IN SEA WATER

Available evidence, summarized in Table 37, indicates that this germ will live in unsterilized sea water in gradually decreasing numbers for periods ranging at least from about one week to one month, depending upon local conditions.

TABLE 37

Observer	Date	Days after infection when germ was last observed
De Giaxa	1889	9
Foote	1895	17
Klein	1896	21
Burdoni-Uffredizzi and Zenobi	1889 (?)	14
Herdman and Boyce	1899	20
Field	1904	10

No observer has noted any signs of the typhoid germ multiplying in sea water.

According to Klein, germs of Asiatic cholera behave in a similar manner in sea water to typhoid germs, except that their continuance of life is apparently somewhat shorter.

Experiments have been made both by Klein and Field in which there was a gradual displacement of the infected sea water by uninfected sea water. The apparent result was a shortening of the life of the typhoid germ, but it is not clear how far this was a matter of elimination from the vessel by displacement of the water containing them.

In all other tests included in the above tabulation the infected sea water remained undiluted.

BACTERIAL CONTENTS OF UNPOLLUTED SEA WATER

Numbers of Bacteria.—Far distant from the land the water of the ocean, while by no means sterile, contains comparatively few bacteria, and all of these appear to be of a harmless kind. Thus, Levin found during an expedition to the Arctic regions that the water in that locality, according to the average of numerous analyses, contained 11 bacteria per cubic centimeter. This number he compared with 700 per cubic centimeter as the contents of sea water off the shores of Sweden.

In mid-ocean, in a voyage across the Atlantic, Minervini found that the numbers of bacteria ranged from 8 to 140 per cubic centimeter, and averaged about 60 per cubic centimeter. That these samples were not sterile is not so surprising as might appear at first sight, as the flora and fauna of ocean waters naturally furnish food for bacterial life. Thus Minervini records that in mid-ocean several tests of the organic matter in sea water showed about 25 parts per million of oxygen consumed according to the Kubel method.

These numbers found in the middle of the Atlantic ocean correspond quite closely with those found about 2.5 miles or more distant from the coast by Russell in the Gulf of Naples and by Carta in the Gulf of Genoa.

The sediment on the bottom of the ocean was studied by Russell, and found to bear quite a close relation to the relative numbers in the water above, when the distance from shore exceeded that covered by the zone showing immediate effect of

shore pollution. Within this zone, showing gradually decreasing effect of pollution, numerous bacteria were naturally found in the sediment.

Fisher also made numerous examinations of sea water on a prolonged ocean voyage to the Antilles, and found the bacterial contents to be generally similar to the above.

Tests for Bacillus Coli.—Bacillus coli is the principal species or group, and by far the most abundant in the intestines of man and other warm-blooded animals. Waters in which this germ is regularly absent in from 1 to 10 cubic centimeters are found to be quite unpolluted, while the pollution of waters is now quite generally measured by the comparative numbers of bacilli coli present, according to methods formulated both in America and Great Britain. At the Havana meeting of the American Public Health Association in December, 1911, it is understood that it was agreed to adopt certain tests to differentiate true B. coli from other members of this intestinal group of bacteria. Present literature generally refers to B. coli, not as a distinct species, but as a rather broad group of intestinal bacteria, especially if the "presumptive test" is employed.

The evidence is decisive that unpolluted sea water, remote from source of pollution, contains no bacillus coli. The most complete tests available were made for the Royal Commission on Sewage Disposal by Dr. Houston. Of thirty-five samples of sea water collected off the coast of Scotland within sight of land, but distant from any appreciable local pollution, thirty-four were found to contain no bacillus coli, even when 100 cubic centimeters portions were examined. The remaining sample gave a positive test with 10 cubic centimeters.

This evidence is in general accordance with the result of studies as to the distribution of numbers of bacteria and of bacillus coli, which have been made in this country of the waters of the Great Lakes some distance from land.

Influence of Fish.—The question of fish comes up for consideration, with reference to bacillus coli being found in sea water at points considerably removed from sewage pollution. The evidence upon this point is not as complete as desired, but the observations of Amyot and Whipple indicate that bacillus coli is not a normal inhabitant of the intestines of fish. The studies of Russell and Bassett leave the matter in doubt, but Johnson found that where fish live for some time in polluted waters the

intestines of the fish contain this germ. On the whole it is quite apparent that in unpolluted sea water bacillus coli coming from fish does not interfere seriously with the proposition that this germ is absent from such water.

Influence of Birds.—While the fecal discharges of birds contain bacillus coli, the influence of this factor is apparently negligible, as a general proposition, upon the normal contents of deep sea water. Exceptions could appear only in chance samples, which are always to be avoided, as they are apt to lead to errors.

Influence of Boats.—Refuse matter discharged from boats, in the opinion of some, is entitled to some weight as a factor influencing the quality of deep-sea water. At intervals this is probably true for small volumes, but the effect of such would be hardly appreciable in a comprehensive set of examinations.

Generally speaking, we may say that deep sea water, distant from local sewers, is unpolluted according to bacillus coli tests.

BACTERIAL CONTENTS OF OYSTERS AND OTHER SHELLFISH TAKEN FROM UNPOLLUTED WATERS

Exhaustive investigations upon this subject show that normally the oyster and other shellfish contain not only no specific disease germs such as that of typhoid fever, cholera, etc., but no bacillus coli, which, as already stated, is the prevailing organism in the intestines of man and other warm-blooded animals.

Prof. C. A. Fuller, formerly of Brown University, Providence, R. I., examined most carefully various portions of each of 200 oysters taken from unpolluted sources, as well as the liquid contained in the shell. In no instance did he find any bacteria which could be classed with the bacillus coli group.

Clark and Gage, who investigated this matter extensively for the Massachusetts State Board of Health, concur in this conclusion, that bacillus coli is not a normal inhabitant of either clams or oysters.

Investigations leading to the same general inference have been made in various laboratories abroad, among which may be mentioned those of Klein, Houston and Hewlett.

In regard to the numbers of bacteria contained in the alimentary canal of oysters, Herdmann and Boyce found from 0 to 5 in deep-sea oysters when testing on agar. Oysters from shops contain from 1 to 1200 on agar, and from 1700 to over 20,000 on sea-water gelatine.

Ayers studied the oysters from several markets in Chicago and found colon bacilli in oysters from five out of nine markets. From the same market, some lots showed sewage pollution while others gave no such sign, having come from another source.

LIFE OF TYPHOID FEVER GERMS IN LIVE OYSTERS IN SEA WATER

Evidence upon this proposition has been obtained by several observers by putting oysters from unpolluted sources into small receptacles containing sea water infected with typhoid fever germs. From time to time examinations were made of the tissue, pallial cavity, alimentary tract, shell water, etc., of the oysters. All observers have found that these disease germs penetrate the oyster body and live there in gradually decreasing numbers for various periods, ranging from about one week to about one month. In no case has any one observed any signs of multiplication of typhoid germs within a live healthy oyster.

The principal data available upon this point are summarized in Table 38:

TABLE 38

Investigator	Date	Period (days)	Remarks
Foote	1895	30	Lived longer in oyster than in water.
Chantemesse	1896	2	
Klein	1896	17	No record of period of elimination.
Herdman and Boyce	1899	14	Lived longer in water than in oyster.
Field	1904	9	

In each case there is doubt about all of the typhoid germs having died within the period given; the records simply show the period up to the time when it was last observed.

Attention is called to the fact, as noted in the table, under "Remarks," that the comparative life in water differed with the different observers. Generally speaking, the life of the typhoid germ within the oyster was found to be very similar to that in sea water, as shown in Table 37 and the remarks made in that connection are also applicable here.

Herdman and Boyce made tests to ascertain how long a period was required in which to remove typhoid germs from infected oysters by subjecting them to a running stream of pure sea water. In seven days they found practically a total disappearance.

Field found, upon changing each day the infected oysters to a new clean tank of uninfected sea water, that the specific germ within the oysters (and also clams) could not be found after four days.

In each of the latter tests it is to be noted that the period was about one-half of that observed where the oysters remained in the originally infected water.

As large numbers of typhoid germs were used in infecting the oysters in these tests, under conditions less favorable from a sanitary standpoint than ordinarily occurs in nature, these data show in this regard abnormally long periods of life. How far this aspect of the case goes to offset limitations in laboratory methods for the detection of the specific germ is a question which cannot be decided readily.

LIFE OF TYPHOID GERMS IN DEAD OYSTERS

Field notes in the *Medical News*, Vol. LXXXV, page 571, the result of some experiments in which he observed a well-defined growth of typhoid-fever germs in some dead and dying oysters in sea water. These oysters were infected with enormous numbers of typhoid germs, and the conditions of the test would in this regard be rarely, if ever, duplicated in nature. The great mischief which could be done by one dead infected oyster among a lot of oysters suggests at once that this matter should be investigated most thoroughly.

This possibility of growth of typhoid germs on dead shellfish is accepted by Dr. Niven and mentioned in his testimony before the Royal Commission, but the evidence to support it seems to us to be very limited.

Klein makes no mention of this question, but he records some observations indicating that the typhoid germ may multiply in cockles.

The question of growth of typhoid germs on cooked oysters, in instances where some but not all of these bacteria in a lot of infected oysters are killed by cooking in the same receptacle, is a matter worthy of serious thought.

The antagonism of other kinds of bacteria toward the typhoid germ is a very important factor in this connection, as it is quite possible that the ordinary kinds of bacteria present in an oyster at its death might with their toxic products normally prevent any appreciable growth of typhoid germs.

RESISTANCE OF TYPHOID GERMS TO HEAT

While typhoid germs form no spores and are killed by heat, it is not probable that heat as ordinarily applied in cooking oysters is nearly as great a safeguard against infection as is believed to be the case by many. Thus, Niven recognizes this in reviewing the data secured at Manchester, and Herdman and Boyce advise that oysters should be sufficiently cooked, that is, raised to the boiling-point and kept there for at least 10 minutes. Clark and Gage found that while exposure for 5 minutes to a temperature of 55° Centigrade killed the great majority of typhoid germs, a few survived a temperature even of 80° Centigrade. In some interesting experiments made by Hill it was found that the cooking of oysters as ordinarily practised usually but not invariably killed typhoid germs.

An instructive report along this line of thought is that by Dr. Hamer, producing plausible evidence for attributing an outbreak of typhoid fever in certain districts of London, late in 1903, to fried fish. In Health Officer Murphy's letter of transmittal reference is made to similar outbreaks officially reported in 1898 by Health Officer Annes, of Huddersfield, and in 1899 by Health Officer Williamson, of Sandal Magna.

RELATIVE VITALITY OF BACILLUS COLI AND BACILLUS TYPHOSUS IN WATER

The longevity in water of these two species of bacteria is considered by bacteriologists to be quite similar. Bacillus coli is believed by some to be slightly more hardy and to live a trifle longer in water, although Houston found bacillus coli only after seven or eight days upon making a test with pure sea water artifically infected with this germ.

So far as this feature is concerned, the prevalence of bacillus coli appears to form a satisfactory general index for pollution, both in shellfish and in the water surrounding them.

POLLUTION ON THE OUTSIDE OF OYSTERS

Naturally there is much sediment, including bacteria, which is deposited from the water on to the beds in which oysters and other shellfish grow. From the sanitary standpoint it is significant that in the investigation of the outbreak of typhoid fever at Lawrence, L. I., Dr. Soper found by analysis that while 20 per cent. of the oysters were certainly polluted on the inside, as many as 70 per cent. were polluted on the outside of the shell. The widespread significance of this is that as the oysters were placed on the market, polluting material from the shells of a few oysters very likely, under some circumstances, might seriously pollute oysters which otherwise would be perfectly safe. Whether or not this is generally true, or applicable only to the particular conditions in question, needs further careful study.

RELAYING OF OYSTERS

For many years it has been the custom in France to relay oysters in disgorging tanks for a short time, with the view to causing the disappearance of disease germs before the oysters are placed on the market. This proposition was investigated in 1895 by Profs. Herdman and Boyce, and as the result of their observations they recommended that before the oysters are placed on the market they should be allowed to remain for a short time in water of unsuspected and well-established purity. There is unquestionably much merit in this proposition, as was testified to by a large number of competent observers in the hearings held by the Royal Commission on Sewage Disposal. As to the period of time required for polluted oysters to free themselves from all objectionable bacteria, the evidence is not conclusive. Most observers think that it would be safe to make the period two weeks, while a few prefer a period of three or even four weeks. Taking everything into consideration, the Royal Commission, while recognizing the importance of the relaying of shellfish, not only from the point of view of public health, but also from that of the oyster trade, did not feel disposed to commit itself upon the practicability of the method, but strongly recommended further investigations of the matter. Dr. Stiles, of the Bureau of Chemistry of the United States Department of Agriculture, has studied this question.

SANITARY CONDITIONS AS SHOWN BY INSPECTION OF LAYINGS OF OYSTERS AND OTHER SHELLFISH

During the past fifteen years it is safe to say that a majority of the more prominent oyster beds, fattening grounds, etc., in this country and elsewhere have been examined with considerable care, either by official sanitary inspectors or by those who are competent to form a reliable general opinion as to their sanitary significance.

Similar attention has also been given to other shellfish, especially clams, the life history of which is more or less similar to that of the oyster. The reports of the Rhode Island Commissioners of Fisheries contain many interesting features about mode of growth, etc., of clams, particularly of the soft-shell variety.

Sanitary conditions can be adequately decided upon when the surroundings obviously show freedom from all pollution or when the sources in question are very seriously and objectionably polluted. Unfortunately, many oyster layings come within the intermediate class, generally spoken of as "doubtful," and about which it is difficult to arrive at a correct and reliable opinion as to the probable degree of pollution on some occasions. Concerning this doubtful class, it is to be stated that information should cover reliably a wide range of conditions as to wind, weather, currents, and in general take into account all of the physical conditions, both subjectively and objectively, which bear a relation between population serving as a possible polluting factor and the body of water or beds serving for the cultivation of oysters or other shellfish.

Dr. Bulstrode, in his classical report "On Oyster Culture in Relation to Diseases," published in 1896, presented the first comprehensive record of the condition of practically all the oyster layings on the English and Welsh coasts. In these sanitary surveys very careful attention was paid to the various physical factors involved in the premises, and which, taken collectively, record in full what the English sanitarians speak of as "topographical conditions." Numerous maps were included in Dr. Bulstrode's report to facilitate an understanding of the actual conditions found. To appreciate fully the contents of this excellent report it is necessary to refer to the original. Here it is sufficient to say that many of the oyster layings were in such sanitary surroundings as to make it obvious to the investigator

that the oysters or water from these sources were not of a perfectly safe hygienic character.

SUMMARY OF EVIDENCE AS TO SHELLFISH POLLUTION

Effect of Pollution.—The evidence already presented leaves no room for reasonable doubt that to a limited degree typhoid fever is transmitted by oysters, clams and some other shellfish which become infected in sewage-polluted waters. Asiatic cholera can be similarly transmitted. Where oysters or other shellfish are excessively polluted, it appears that severe intestinal disorders, such as gastro-enteritis, may result within a comparatively few hours after eating the shellfish.. The nature of the disease varies with the individuality of the person and the nature and extent of the pollution. This has been shown by some persons of a party, eating polluted shellfish from the same source, having had intestinal disorders of varying severity within a few hours, while others of the same party contracted typhoid fever in about ten days later after the ordinary period of incubation of typhoid germs.

Careful and prolonged studies at London, Manchester and several other large cities in England led to the conclusion that in the neighborhood of 10 per cent. of the total cases of typhoid fever in those cities has been caused by eating polluted shellfish. Along the British seacoast at quite a number of summer resorts the proportion is far greater than that above stated. In this country the extent to which polluted shellfish cause disease and death is not known definitely. It no doubt varies widely in different places and during different seasons in the same place. The fact that shellfish are eaten more generally in this country than in Great Britain, and that quite a portion of the shellfish are taken from polluted waters, suggests the possibility that the public health is more menaced in this way here than abroad.

There are those who still believe that polluted shellfish cut very little figure, generally speaking, as regards the public health. Some of these persons appear to have formulated their views without knowledge as to general experiences or the evidence upon the subject. Others for commercial reasons attempt to minimize the evidence, and class it as a whole with some statements and conclusions which are obviously of questionable accuracy.

There has been a substantial harmony in the conclusions reached by all who have investigated the subject carefully. The rumor appearing in medical journals in 1905, of a French commission reporting to the Secretary of the French Navy that oysters could not transmit typhoid fever, was found to have been in error when the official report was carefully examined.

DO SHELLFISH HIBERNATE?

In the second progress report of the Committee on Standard Methods of Shellfish Examination presented to the laboratory section of the American Public Health Association, Dec. 4, 1911, reference is made to an important fact learned during the past year. Reference is made to the seasonal changes in the bacteriological condition of oysters, which is apparently independent of the sanitary condition of the beds. It has been found as a result of the tests suggested by the Committee and found on pages 575–81 of the *Journal of the American Public Health Association* for August, 1911, that the same oyster beds show different results at different seasons of the year. Almost invariably the bacterial contamination has been less during the winter than at other seasons. The difference has been striking in some instances. The phenomenon appears to be the same along the Atlantic Coast from Virginia to Massachusetts. Further data are desired before final conclusions are drawn, but the indications are that this seasonal difference is associated with the hibernation of the oyster. If it is true that the oyster maintains itself in a resting state during the winter and the shell is kept closed so that no water enters it, then objectionable bacteria of sewage origin, if found in the oyster at all, can be explained only by having been entrapped in the shell before hibernation began. The length of life of typhoid germs in the oyster would then be a factor of greater importance than hitherto considered.

The Committee speaks of this question conservatively and closes its discussion with the statement that if the results thus far obtained are to be trusted it may be fairly said that oysters harvested from the first of December to the first of April are much safer for use than those harvested early in the autumn or late in the spring. The duration of hibernation and the corresponding period of winter immunity will naturally vary under different local conditions.

POSITION OF STATE AUTHORITIES ON QUESTION OF SHELLFISH POLLUTION

The Massachusetts State Board of Health devoted five years to investigating the use of shellfish from the polluted waters of Boston harbor and vicinity. In the 1905 report of the Board is contained a careful description of conditions then obtaining, as stated in the report of the Chief Engineer, Mr. X. H. Goodnough (pages 413–26). The chemist of the Board, Mr. Clark, also details the results of his excellent studies on the bacteriology of the shellfish from these layings on pages 429–57.

While the above-mentioned details are important to the specialist, they are probably of less interest to the general reader than is the conclusive report by the Board to the Legislature. This finding is given on page 16 of the 1905 report and is as follows:

FINDING OF MASSACHUSETTS STATE BOARD OF HEALTH IN BOSTON HARBOR

From the investigations made by the officers of the Board during the past five years, we find reason to conclude that oysters, clams and other shellfish, when grown in unpolluted water, are free from bacteria or other organisms which we associate with disease-producing germs; that when grown in or when exposed for a short time to sewage-polluted water, these shellfish take into the water within their shells and into their bodies the sewage bacteria that are associated with such disease germs; that the methods of keeping such shellfish in the market do not destroy these bacteria; that the eating of shellfish which have been in sewage-polluted water is likely to be injurious to health and to endanger life. This is especially the case if they are eaten raw, and the danger is not removed by the usual methods of cooking, such as the steaming of clams, the making of oyster stew or even the frying of oysters. Sufficient cooking to insure the destruction of the dangerous bacteria renders the shellfish unpalatable. The only safe method is to use clams and oysters that have grown and have been fattened in water unpolluted by sewage.

The careful survey of Boston harbor, reported in the Supplement, indicates that no part of it is sufficiently free from sewage pollution to be a safe place for growing or fattening clams or oysters.

Of still more importance was the step taken by the Board in requesting the Fish and Game Commissioner to prohibit the taking of shellfish from Boston harbor and vicinity. This request is stated on page 55 of the 1906 report, as follows:

PROHIBITING THE TAKING OF SHELLFISH IN BOSTON HARBOR

Late in the year, as a result of its investigations relative to the character of the water of Boston harbor and the shellfish taken from the flats therein, the Board, acting under the provisions of Chapter XCI, Section 113, of the Revised Laws, requested the Fish and Game Commissioners to prohibit the taking of shellfish in Boston harbor, including the tributaries of the Charles, Mystic and Neponset rivers, the Chelsea river and Dorchester and Quincy bays, inside, or west, of a line drawn from Nut Island to Prince's Head; thence along the bar from Prince's Head to Peddocks Island and through Peddocks Island to the northeasterly end thereof; thence to the southeasterly point of Deer Island and through Deer Island and across Shirley Gut to Point Shirley, excepting along the Winthrop shore inside, or northeast, of a line drawn from the outer end of the steamboat landing of the Point Shirley Club at Point Shirley to the outer end of the Cottage Park Yacht Club wharf on the southerly shore of Winthrop between Orlando and Woodside avenues; and to prohibit also the taking of any such shellfish about the shores of Lovell's, Gallup's and George's islands, until you receive further notice from this Board.

The New Jersey State Board of Health, since its reorganization in the spring of 1908, has proceeded actively in correcting difficulties as to polluted shellfish. This is shown most clearly in the graphic report of Mr. H. M. Herbert, formerly Chief of the Division of Sewerage and Water Supplies, on pages 266–69, of the 1908 Report of the Board, as follows:

CONTROL OF SHELLFISH POLLUTION IN NEW JERSEY

There is another feature which is worthy of serious consideration, as it involves millions of dollars. The people generally throughout the country have awakened to the fact that a number of typhoid fever epidemics were caused by the use of infected shellfish and they are demanding a safe article of food. Already a number of our sister states require, or are formulating requirements, that only clams and oysters taken from comparatively unpolluted beds shall be exposed for sale within the territory under their jurisdiction.

The New Jersey shell fisheries are already beginning to feel the effects of this movement which is still only in its infancy, but is growing rapidly. The Amboy bay oyster is scarcely heard of to-day; the luscious Shrewsbury oyster, which fifteen years ago was the delight of epicures, is left to fatten and rot in the bed of the river; that king of bi-valves, the Shark river oyster, is only a memory and, owing to the failure of our State to provide a proper sewage disposal plant at the Sea Girt camp

grounds, the Manasquan clam, one of the finest taken from our waters, can no longer be used with impunity.

The same is true to a greater or lesser degree regarding the majority of the clam and oyster beds situated in other sections of the State. The summer population at the southern sea coast resorts is rapidly increasing, and there are now no less than eleven municipalities, including Atlantic City, discharging raw sewage into the thoroughfares and bays which line this section of our coast, and which are either artificial or natural clam and oyster beds.

Perhaps the best-known and most popular Jersey oyster of the day is the Maurice cove, which derives its name from the vicinity in which it is grown. Raw sewage from Millville is discharged into the Maurice river about eighteen miles above, and what seems incredible, the very men engaged in the oyster business have privies and water-closets discharging their contents over and near the floats where the shellfish are stored, as shown by accompanying views.

At the mouth of the Delaware river and in Delaware bay are located, probably, the largest oyster fields north of the Chesapeake bay. No one will deny that the Delaware river is more or less polluted below Philadelphia. The average flow of the Delaware river at Philadelphia during the driest month (see Geological Survey of New Jersey, Volume III, page 309) does not exceed one billion, two hundred and eighty-three million gallons per day and the estimated amount of raw sewage discharged into the river and its tributaries above and including Philadelphia and Camden is one hundred eighty-eight million, seven hundred and twenty-one thousand gallons per day, which would give a proportion of one part of sewage to six and eight-tenths parts of the river water. It should be borne in mind that owing to the deforestation of the upper watershed, the flood flow is increasing and the dry weather flow diminishing, while at the same time, the amount of sewage is increasing at the rate of about 30 per cent. in ten years. This latter is a constant factor and does not vary as the flow of the river. Below Philadelphia there is an additional 25 million gallons of sewage emptying into the river from New Jersey, Pennsylvania and Delaware. Unless this gross pollution is checked in the near future, the water of the Delaware river will not only be unfit for domestic use but also worthless for the production of shellfish. Can the State allow this to continue?

The annual amount realized from the sale of our shellfish is about 3 millions of dollars. At least two-thirds of these come from the Delaware river and bay and 2 millions of dollars, the value of one year's product, would under a conservative estimate install sewage purification plants on all the systems in this state, which are now discharging raw sewage into the Delaware river.

It is fast approaching the condition of the Passaic river which still remains a disgrace to our State.

Inspections have been made covering 632 miles of riparian frontage on the Delaware, Raritan, Rahway, Elizabeth, Rockaway, Shark, and Shrewsbury rivers and their tributaries, together with the lakes along the Monmouth county seashore; 808 individual or minor pollutions, were discovered and reported upon. These were acted upon by the Board and 698 notices to cease polluting were served. One preliminary injunction was granted against an individual polluter, and twelve more cases have recently been placed in the hands of the Attorney-general for action.

Dr. Porter, State Commissioner of Health of New York, had his staff study this subject at some length during the summer of 1908, as stated in his report for that year, Vol. II, pages 833–92. The field was so large for the facilities at hand that no positive conclusions were drawn. The detailed records show, however, evidence of some sewage pollution at many of the leased and private oyster grounds on Long Island.

The United States Government has given this question some attention, as first shown in the appendices of the 1904 Report of the Commissioner of Fisheries. He states that the Great South Bay on the southern coast of Long Island, from which the so-called "Blue Point" oysters come principally, showed opportunities for pollution, especially in the floats near shore, although the oysters actually analyzed were free from sewage pollution.

U. S. BOARD OF FOOD AND DRUG INSPECTION

This Board has considered the shellfish question and rendered three decisions, the full text of which is as follows:

F. I. D. 110. Issued October 15, 1909.

UNITED STATES DEPARTMENT OF AGRICULTURE

Office of the Secretary

Board of Food and Drug Inspection

FOOD INSPECTION DECISION 110

Shellfish

This Department has investigated the preparation and shipment of oysters, clams, and other shellfish. A public hearing on this subject was held by the Board of Food and Drug Inspection on May 20, 1909. At this hearing, growers, packers, dealers and the public were afforded an opportunity to be heard.

It is unlawful to ship or sell in interstate commerce oysters or other shellfish taken from insanitary or polluted beds. The pollution of oysters with sewage can readily be detected by bacteriological examination, and such polluted oysters or other shellfish are adulterated under Section 7 of the Food and Drugs Act of June 30, 1906, in that they contain an added "poisonous or other deleterious ingredient which may render such article injurious to health."

It is unlawful to ship or sell in interstate commerce oysters or other shellfish which have been subjected to "floating" or "drinking" in brackish water, or water containing less salt than that in which they are grown. Such food is adulterated under Section 7 of the law because a substance "has been mixed and packed with it so as to reduce or lower or injuriously affect its quality or strength." There can be no objection to "drinking" shellfish in unpolluted water of the same salt content as that from which they have been removed. Attention is called, however, to the dangers resulting from "drinking" shellfish near polluted fresh water streams and near other sources of pollution.

It is unlawful to ship or to sell in interstate commerce shucked oysters to which water has been added, either directly or in the form of melted ice. Such food is adulterated under Section 7 of the act because a "substance has been mixed and packed with it so as to reduce or lower or injuriously affect its quality or strength," and also because a "substance has been substituted wholly or in part for the article."

The packing of shellfish with ice in contact may lead to the absorption by the oyster of a portion of the water formed by the melting ice, thus leading to the adulteration of the oysters with water.

Only unpolluted cold or iced water should be employed in washing shucked shellfish, and the washing, including chilling, should not continue longer than the minimum time necessary for cleaning and chilling.

In view of the fact that the shipping season has begun and shippers will require several months to provide themselves with suitable containers for the shipment of shellfish out of contact with ice, no prosecutions will be recommended prior to May 1, 1910, for the shipment or sale in the interstate commerce of oysters or other shellfish because of the addition of water caused solely by shipment in contact with ice.

H. W. WILEY,
F. L. DUNLAP,
GEO. P. MCCABE,
Board of Food and Drug Inspection.

Approved:
W. M. HAYS,
Acting Secretary of Agriculture.
Washington, D. C., October 14, 1909.

F. I. D. 121. Issued June 4, 1910.

UNITED STATES DEPARTMENT OF AGRICULTURE

Office of the Secretary

Board of Food and Drug Inspection

FOOD INSPECTION DECISION 121

Floating of Shellfish

Amendment to F. I. D. 110

Considerable evidence has been submitted to the Department since the issuance of Food Inspection Decision 110 on the practice of floating or drinking oysters in water of less saline content than that in which they were grown to maturity.

Full consideration has been given to all the hearings and to the briefs and other information submitted subsequent to the hearings and the Board is of the opinion that it is not improper to drink oysters in water of a saline content equal to that in which oysters will grow to maturity. If, however, oysters are floated in water of a less saline content than that in which oysters will properly mature, the packages containing such oysters must be very clearly and legibly labeled "Floated Oysters," otherwise they will be considered adulterated under section 7 of the law.

Particular attention should be paid by the growers and handlers of oysters to the character of the water in which the oysters are brought to maturity or floated. Where such waters are polluted it will invariably follow that the oysters will also partake of this pollution and subsequent washing of the oysters, or even floating in water which is not polluted is likely not to cleanse them of this pollution.

Oysters found in interstate commerce in a polluted condition because of the character of the water in which they are grown or floated are adulterated under the Food and Drugs Act.

F. L. DUNLAP,
GEO. P. MCCABE,
Board of Food and Drug Inspection.

Approved:
JAMES WILSON,
Secretary of Agriculture.

Washington, D. C., May 14, 1910.

TENTATIVE

FOOD INSPECTION DECISION, DEC. 1911

Floating of Oysters

Superseding F. I. D. No. 121

Our investigation of the methods of handling oysters or other shellfish and results of those methods in the character of the product placed

on the market, have demonstrated the fact that the practice of floating oysters and other shellfish results in their adulteration by the addition of water. It is found also that floating gives to the oysters and other shellfish a fictitious appearance resulting in the deception of the consumer. Moreover, the water in which oysters or other shellfish are floated being of lower salt content than the water in which they were grown, is usually in the mouth of streams or artificial inlets surrounded by houses and is almost invariably polluted.

Again, further information discloses the fact that the expression in Food Inspection Decision No. 121, "in water of a less saline content than that in which oysters will properly mature" is impossible of interpretation owing to the fact that oysters or other shellfish which have been accustomed to water of a very low salt content appear to mature in water containing less salt than is the case with oysters or other shellfish taken from saltier water. Therefore, oysters or other shellfish shipped in interstate commerce after being floated in water of a lower salt content than that from which they were taken, will hereafter be regarded as adulterated under the Food and Drugs Act. The shipment of oysters or other shellfish taken from or treated with polluted water or which are shown by examination to be polluted, is in violation of the Food and Drugs Act.

Food Inspection Decision No. 121 is hereby superseded and Food Inspection Decision No. 110 reaffirmed in its entirety.

These decisions have attracted much attention from the oystermen and the various State Boards of Health having such matters in hand.

The findings of the U. S. Dept. of Agriculture, Bureau of Chemistry, in these matters are set forth in *Bulletin* 136 of that Bureau. The letter of transmittal and a summary of the report are given in full, as follows:

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF CHEMISTRY,
Washington, D. C., August 26, 1910.

SIR:

I have the honor to submit for your approval a report prepared by G. W. Stiles, Jr., bacteriological chemist of this Bureau, on the contamination of shellfish by sewage-polluted water. The data reported are based on an extensive and painstaking investigation during which many localities have been inspected, the conditions carefully studied, and all the bacteriological data possible obtained. The latter were found to corroborate the observations made during inspection. To no one, not even the consuming public, will this report be of greater interest

and benefit than to the industries concerned. That the danger noted exists to some degree in many localities no one can deny, and that the danger is one that will increase unless intelligent and efficient measures are taken to control it is equally obvious. The investigations presented in this manuscript are of direct importance to a proper consideration of such steps as may be indicated under the food and drugs act to protect the public health, and to avoid deception. The report is in no sense intended to discredit the valuable industries concerned, but rather to point the way in which the products of these industries may be accepted with greater confidence by the public. It is believed that this report will assist in the furtherance of this purpose, and I recommend that it be published as *Bulletin* 136 of the Bureau of Chemistry.

Respectfully,

H. W. WILEY,
Chief of Bureau.

HON. JAMES WILSON,
Secretary of Agriculture.

Summary.—(1) There is undisputed evidence to show that shellfish become contaminated when placed in sewage-polluted water, and that *B. coli* and *B. typhosus* will survive for variable lengths of time in the liquor and the body contents of such shellfish after their removal from infected water.

(2) The presence of sewage organisms in oysters and other shellfish, even in small numbers, may be indicative of great danger; for, where such organisms exist, the specific cause of enteric fever and allied disorders may also be found.

(3) The results of many investigators show that sewage-polluted shellfish have been responsible for the production of typhoid fever and other intestinal diseases. The most noteworthy cases appear to have occurred from eating oysters which had been floated in sewage-polluted water, although instances are cited where shellfish infected by polluted water, either in their natural or artificial beds, have also been the vehicle of disease transmission.

(4) The shellfish industries of this country are extensive and important, comparing favorably with other industries concerned with the production of food materials. A valuable article of food is furnished to millions of people by these industries, and thousands of individuals find profitable employment in developing and carrying on this business in all its phases.

(5) The indiscriminate introduction of sewage into our natural bodies of water is now the greatest enemy to the shellfish industries. In order to correct this evil it will be necessary to prevent further pollution of our waters, or else to remove the shellfish industries from the grounds subject to pollution.

(6) Oyster beds should be protected from every possible source of contamination, and they should be located in water proven to be pure by repeated examinations. These examinations should consist of careful bacteriological and chemical analyses of both the water and oysters from oyster layings. The laboratory findings should also be supplemented by systematic inspection of all the territory which could in any wise affect the condition of the water flowing over the oyster beds.

(7) The practice of floating oysters in water of questionable purity should be absolutely prohibited because of the probability of sewage contamination. When it is desired to remove the gross filth from the exterior of the shell, oysters may be floated and allowed "to cleanse themselves" in suitably constructed devices in waters free from pollution, and containing no less salt than the water in which they will grow to maturity.

(8) Like other perishable food products, oysters may become unfit for use if stored or kept under insanitary conditions. This spoilage, however, may take place from the length of time out of water.

(9) Oysters removed from pure beds may become contaminated during the process of shucking or preparation for the market in insanitary shucking establishments. These places should be constructed in a sanitary manner and provided with satisfactory appliances for the proper cleansing and sterilization of utensils used for shipping oysters. Without such devices it is almost impossible to prepare packages in a sanitary manner. This is particularly true when cans, barrels, or containers of any kind are used a second time without proper cleansing and sterilization. When contaminated these unsterile vessels may become active agents for the dissemination of disease-producing organisms.

(10) The liquor in the shell surrounding the oysters contains more bacteria than does an equal volume of meat from the same oyster. This liquor, together with any sand in the gills of the oyster, can be removed and the meat chilled at the same time by the use of pure ice and water. This washing process can be done efficiently within 3 to 10 minutes, depending upon the method employed. Oysters should not be allowed to soak in fresh water, as they increase in volume, change in appearance and flavor, and decompose more rapidly than those not soaked.

(11) Steaming contaminated oysters and clams in the shell, or cooking them after shucking for 15 minutes at boiling temperature, practically destroys all organisms of a questionable character, but since in practice shellfish are never cooked for this length of time, cooking cannot be depended upon to remove this danger.

(12) Oysters intended to be eaten on the half shell, above all others, should be produced from beds of unquestionable purity, and they should be consumed preferably while fresh from the beds; although if properly kept at cool temperatures under sanitary surroundings shell oysters

may remain wholesome and in good condition for several weeks after dredging.

(13) The investigations show that vast areas of valuable shellfish grounds in this country are now reasonably free from sewage pollution, but this territory will gradually diminish in size if sewage is not properly cared for in the future. Comparatively speaking only a small acreage is now subject to serious pollution. Active steps are now being taken in some instances to overcome this difficulty; however, it is not the satisfactory conditions which require regulation and future protection, but those places which are polluted at the present time, and yet are being used for the cultivation and sale of shellfish. The presentation of these facts should stimulate every citizen and health officer alike to see that the wastes under their own jurisdiction are not adding to the difficulty of keeping our natural bodies of water and the shellfish therein free from contamination.

The uncertainty as to what the oyster growers should do to meet proposed requirements, is outlined in the following address, delivered at Norfolk, Va., May 18, 1910, before the Annual Meeting of the Oyster Growers and Dealers Association of North America, by Mr. Fred S. Beardsley, Manager of the Stratford Oyster Co. of Stratford, Conn.

THE OYSTERMAN'S VIEWPOINT

It would seem to be unnecessary, before a convention of oyster growers and dealers, to go very much into the history of the oyster business, as it is fair to assume that most of you know quite as much, if not more, about the subject than I do, and were it not that within a few years a new element had been introduced into the subject and new conditions had arisen—conditions that none of us foresaw or could forsee —I would not take up your time and thought by such a review. But these new conditions have been forced upon us, and we cannot help considering why it is that the whole conduct of our business must be changed, and whether the years of experience, careful study, and hard work that we as oystermen, and our predecessors in the business before us have undergone, was time and effort thrown away, misdirected, and at variance with the common laws of business and trade and calculated to do injury to our fellowman in the way of committing a fraud upon him or of tampering with the public health. Why is it that a great industry has had to pause in its progress? Why is it that a hitherto popular and wholesome food has become the object of suspicion and the demand for it materially curtailed, and what is to be the outcome of it all? These are all questions that have been raised by the promulgation of the rules of the Pure Food Department and that from our practical viewpoint

press for answer. In considering these questions, then, it may be well to review briefly the history of the oyster industry as conducted in the past, so that we may get a line, if possible, on the reasons for the new order of things.

From the earliest times in this country people living on the coast have gathered from the waters of our bays and rivers this wholesome food; even the Indians coming down from the highlands and feasting themselves upon this luscious bivalve, as is evidenced by the mounds of shells that are found on the shores. As time went on and population increased, oysters became an article of commerce, those living near the salt water gathering them and shipping them by such means of transportation as were available to more interior points. These oysters for many years were natural growth and were found in greatest abundance near the mouths of rivers and fresh-water streams, where the proper intermingling of fresh and salt gave the water the proper density demanded for propagation and the proper food for the growth, sustenance, and fattening of the crop. It was nature herself that placed the oyster in the mouths of rivers and in bays where it thrived the best, and from the beginning of time until now the fattest, finest flavored, and most sought after oysters have been and are found in localities where this proper intermingling of fresh and salt water obtains.

Oysters have their habitat in water that varies considerably in salt content, in some places, where the degree of salt is quite low, and again where there is quite a large per cent. of salt. But the most prolific sets, the fastest growing oysters, and the fattest and best flavored stock comes from those localities where there is the right intermingling of fresh and salt to suit the fastidious tastes of the oyster itself.

As time went on and the demand for oysters increased new areas were discovered or developed where oysters could be propagated and grown. In some cases the natural seed was transplanted from one locality to another, and it was discovered that the conditions of the water as to salt content in some localities were adapted for oyster propagation, but the bottom in its natural condition did not furnish the bright, clean substances necessary for a couch to which the embryonic oyster could attach itself. This led the enterprising oysterman to take up these waste bottoms and by furnishing an artificial couch during the spawning season to make a hitherto barren waste of sea bottom to bear fruit. In this way thousands of acres of barren bay and river bottoms in the different states were made valuable for oyster cultivation, made to produce an abundant supply of wholesome food for the people, and incidentally made a profit to the developers of the business and brought employment at remunerative wages to thousands of workers. All this progress and development was carried on without the aid of a paternal government, either state or national—in fact, a great deal of it has been done in spite of adverse legislation and public prejudice. While the

government of the United States and the several states have spent large amounts of money in developing the nation's resources of agriculture, horticulture, and mining; while thousands of dollars have been spent and a great deal of time and thought been devoted to the propagation of finny fish in the stocking of streams, and in numerous ways with which all are familiar, the development of the oyster industry, the greatest resource of them all, has been left to the efforts of the individual, and whatever of progress has been made has been made by those men who have been the pioneers in the development of the industry, who have put their money, their thrift, and their energy into pushing out into untried fields, taking all the risks themselves and staking their fortunes in the development of new territory. They have, in the prosecution of their enterprise, followed the natural law of supply and demand, cultivating, raising, and marketing the product that was most sought after and that brought the most favorable prices. They have handled their stock in the way best suited to the trade, matters of cost of transportation, quality of goods, and demand of customers all taken into consideration. So that until a few years ago, when the orders of the Pure Food Department first came to the notice of the oystermen, the business was conducted along the following general lines.

Shell oysters were taken from the beds, in many cases put into floats for convenience in handling, for the purpose of cleaning or for the purpose of giving the oysters a drink of that proper intermingling of fresh and salt water on which they thrive, and then shipped to the customer. The grower and dealer followed that course that put the oysters in the condition most demanded by the trade. If the trade demanded a salt oyster, salt oysters were furnished, or if the customer demanded a fresher oyster, that was supplied. Some localities furnished one variety and other localities furnished the other variety. The buyer always had a choice as to what he would buy and a wide range of localities, and a wide range of quality and price was always at his command. The natural law of supply and demand regulated the trade, and dealers strove to provide that variety most in demand at the best price.

In the prosecution of this business millions of dollars are invested, thousands of hands are employed, and in the aggregate an enormous supply of wholesome food has been provided for the people, and the experience and study of a great many bright and honest men are engaged in handling this business to the end that the consumer should receive a wholesome food at the minimum cost as to handling, transportation, and incidental expense, which add nothing to the intrinsic value of the food, but which perforce are a part of the expense and cost to the consumer. In the early days, when distances were short from the beds to the consumer and when the business was small, oysters were mostly shipped in the shell, but when it became necessary or desirable to ship long distances the cost of transportation in the shell became so

heavy that it brought the price of the oysters so high as to be beyond the reach of the average consumer. The practice of shucking the stock at the coast and shipping it after opening to points interior came into vogue, and to-day the large percentage of oysters used in commerce are handled in this way. For years the oysters were placed in wooden pails or barrels with a piece of ice large enough to insure refrigeration during transit and forwarded to the consumer in the interior. This method seemed to provide the means of getting the stock from the seaboard to the consumer at the minimum cost for package and transportation. During all the years the business increased, the demand from the people for this wholesome food called for more and more. All over this broad land of ours people were eating oysters without a suspicion as to their wholesomeness. From planter to consumer, all through the ramifications of the trade, there was no hint or suspicion that all was not well, and, as a matter of fact, the people were eating oysters with satisfaction and were getting a wholesome, healthful food. The cases throughout the whole country where it has even been alleged that anyone was made sick by eating oysters were few and far between, and the cases where the fault has been brought to the door of the oyster and proven on him are so rare as to be negligible. No other article of food in such general use has a better record, and when compared with milk, drinking water, and many other things, the oyster stands out par excellence as a wholesome, healthful food.

To Summarize.—Up to a few years ago when the Pure Food Department at Washington took a hand, we assume that the combined experience and study of thousands of men engaged in this business for a great many years was worth something. It is fair to assume that the majority of them were honest men engaged in what they believed was a lawful, decent business. It is fair to assume that it was not their intention to perpetrate a fraud on the public by adulteration or by so handling their product that the consumer got an article of inferior quality. Competition in trade would tend to prevent such a custom even if the men who conducted the business were not disposed to do the decent and honorable thing, and it is fair to assume that their experience as to the best methods was worth something.

Such was the condition of things when a few years ago the department at Washington laid down the rules that aimed to revolutionize the conduct of the business. For the first time we learned that shipping oysters with ice in contact constituted an adulteration and that the practice subjects the public to grave danger. We did not believe it then, and we do not believe it now. If it is the law, however, and after being tried out by an unprejudiced tribunal having cognizance of all the facts and having the matter fairly presented by both sides, the ruling is sustained, we will, as law-abiding citizens, abide by the law.

The question as to what kind of a package for shipment shall be used,

whether with ice in contact or by some other method, might well be left to the consumer in the interior and the dealer from whom he buys his supplies. It is only fair to state that there is a large demand for oysters shipped not in contact with ice, and as long as the consumer is willing to pay an advanced price for oysters shipped by this method to cover the extra cost of package and other charges, there is no reason why he should not do so. But that is aside from the question as to whether oysters shipped with ice in contact constitutes an adulteration or not; and if the public has to pay this advanced price, whether they want to or not, they should know that the cause of the advance is to be laid at the door of the Pure Food Department. The trouble with the ruling, however, is that the consumer, whom the department seeks to protect, has no guarantee that stock leaving the shipper in accordance with the rule will ever reach the consumer in the same condition, as the stock inevitably passes through many hands between the two, and the department offers nothing, in the way of protection to the consumer after the goods reach the jobber and retailer. In other words, the shipper is hampered and circumscribed by the rule of the department, while the jobber and retailer is at liberty to tamper with the goods after they are received, and the consumer whom the rule seeks to protect is entirely without protection except as he is protected by the same trade law of supply and demand.

Sanitary Conditions of Beds and Ships and Methods of Handling.— Much is heard these days about the sanitary condition of the waters in which oysters are grown and fattened, and it goes without saying that all persons, whether engaged in the oyster business or not, will agree that all reasonable sanitary rules and precautions should be observed. If it is shown that certain waters are dangerously contaminated in any way, so that the public health is endangered by taking oysters therefrom for use for consumption or sale, the use of such grounds for the purpose should be prohibited, and the department will get cheerful and whole-hearted cooperation from the oystermen to the accomplishment of that end. But a reasonable standard of purity should be established in oysters, as it is in drinking water, in milk, and in other articles of food and drink, and such a reasonable standard should be known by all. Further than that the department should, by examination and investigation, and in the light of a reasonable standard, determine what grounds are below the standard, so that the oystermen may know now, during the season that oysters are being planted for next season's market, just where it is safe to plant and where it is not safe. Thousands of planters are at this moment uncertain as to whether or not the oyster crop that they are now planting will be available for the use of the coming season or not. We understand that the Pure Food Department does not undertake to look after these local matters, but we say that the Agricultural Department spends thousands of dollars every year in

investigating and experimenting with different farm products, and in the development and conservation of our agricultural resources, and we believe that from the standpoint of a government that though this same department is spending thousands of dollars in the development and conservation of its agricultural resources, it is their duty as well to spend some of it in the conservation of this industry, and one practical and effective way of doing it is to make thorough investigations and examinations of our oyster lands and determine definitely which are good and which are not; and if certain of the grounds are being made unfit for the purpose of growing oysters by means of contamination, then it should be the duty of the same government to put an end to the contamination, to the end that this resource may be conserved. There is another view of this same matter that might well be touched upon. The United States government assumes entire control of the navigable waters of the country, superintends commerce, improves rivers and channels, builds breakwaters, maintains lighthouses, establishes harbor lines, and, in general, has entire control of the navigable waters of the country. In the course of river and harbor improvements it spends millions of dollars in dredging out channels, and then allows cities to dump the sewage and drainage into these channels, making it necessary to appropriate further millions to dig out and repair the damage. This dug material is often towed and dumped in the vicinity of oyster beds, and in this way the United States government pollutes the beds and destroys a natural resource by the action of one department, and then by the action of another condemns it. Surely if the United States government owns the navigable waters of the country and spends the people's money in improving them, it has the authority to prevent the undoing of the work, and surely it should not contribute to the wiping out of a great natural resource. Again, if the United States government spends money in propagating finny fish and in stocking streams, it should not allow the purity of the streams to be impaired and the fish so deposited to be killed off by reason of a city or an individual polluting the stream. From our practical standpoint the position of the United States seems inconsistent, and we desire to make this point very emphatic. The Pure Food Department is laying great stress on its desire to protect the public health, but we have not seen or heard of any recommendation from them that the United States clean its own house, or to so conduct its own affairs that the public moneys shall not be worse than squandered or great natural resources be ruined and wiped out by the conduct of other departments of the government. In short, in regard to this matter of the pollution of streams we think that the department should do all in its power to remove the evil, and that in the case of the oyster planter we are entitled to know from the department at the earliest possible moment which lands can be used and which cannot.

Drinking or Floating of Oysters in Waters of Less Salt Content than that in which They are Grown.—The difference in the salt content varies largely in different localities; changes with the change in tides each day. The same locality may be of greater or less salt content on the average, according to whether it is a dry or a wet season, and on the whole the question of salt content is an uncertain and varying condition. If a certain degree of salt content is necessary or desirable in oysters and demanded by the department, the department should set a standard of salt content, so that we can know where we are. Assuming that the water is reasonably pure, we cannot believe that there is any harm in placing oysters temporarily in water that is the natural habitat of the oyster. We cannot believe that water in which oysters set and thrive is an improper place to put oysters temporarily. To illustrate, let us cite a case that is familiar to most of us. Take the Great South Bay. Oysters set and grow naturally at the eastern end of the bay in what is known as Shinnecock Bay, where the water has a very low percentage of salt content. Oysters also set and grow near Fire Island Inlet, at the more western end of the bay, where, on account of the proximity of the ocean, the water is of a very high degree of salt content. Oysters set and grow naturally in this locality, and they set and grow naturally at all points between. Under the rule oysters may be shipped in interstate trade from either of these extreme points directly from the beds, either from Shinnecock on the east or from Fire Island on the west or from any intermediate point. But under the rule oysters may not be removed temporarily from Fire Island Inlet to any point further east, and then shipped, but may be removed from Shinnecock Bay to any point further west temporarily, and then shipped. In other words, take three given acres adjoining each other at any point to the eastward of Fire Island and to the westward of Shinnecock. On one acre are oysters that are grown there for say a period of three months or longer, and on an adjoining acre are oysters that have been placed there from Fire Island for a period of 48 hours, and on the third acre are oysters that have been placed there for 48 hours from Shinnecock. From two of these acres, that on which the oysters have grown for three months and that on which oysters have been brought from Shinnecock, oysters may be taken and sold in interstate trade, and from the other acre if oysters are so taken and sold the party so doing is guilty of a misdemeanor. From a practical standpoint we say this is unreasonable, and we do not believe would be sustained by an impartial court having before it all the facts. In the very nature of the conduct of the business as we understand it, it is necessary that oysters should be laid down on these grounds or be put into floats at places convenient to the shops and for many reasons, in order that the shells may be washed clean for shipment; that the oyster may clean itself of sediment, so that it will keep in good condition during shipment; and that a supply for filling orders, during stress of weather,

may be readily at hand. The fact that some person may prefer a salt oyster or a fresh oyster should not enter into the case; but the question is what degree of salt content is necessary to make the oyster suitable for sale; and can it be held that oysters are adulterated when placed temporarily in water which is their natural habitat and in which oysters set, grow and thrive. The whole testimony of the oyster dealers is that it will be an injury to the business if oysters cannot be put into floats temporarily; that for the reasons indicated the practice is desirable. The testimony of the dealers is that the oysters are improved by the process, and that the demands of the trade warrant them in the belief that oysters are more desirable when handled in this way, and we believe that the weight of testimony should have some effect on the position of the department. If, however, the department will not pay any attention to the testimony adduced, if the department is not willing to set a standard of salt content, then there is nothing left to do but to make a test case, and ascertain whether the position of the department is sound or not. From a practical standpoint it looks as though there should be some modification of their rule by the department, and it certainly is of such vital importance to the oystermen that all the resources at their command should be used to bring about such a modification as will permit their doing business. A practical viewpoint of the whole question is that a standard of the degree of salt content necessary in oysters should be established if it appears that some certain degree of salt content is necessary or desirable, and that they show us, if possible, why the natural habitat of the oyster is not a proper place to put the oyster temporarily; that the department has made its rulings without exhaustive study of the subject; that the testimony of the oystermen has not been given fair and proper weight; that while in regard to matters of sanitation the department is moving in the right direction and deserves the cooperation of the oystermen, that in all fairness the department should lend every assistance to the prosecution of the industry, first, by establishing a fair and reasonable standard of purity, and then by investigating and determining in the light of such reasonable standards the localities which can be safely used and which cannot; that the department should make every effort to stop pollution to the end that this valuable resource may be conserved; that it should recommend to Congress the passage of laws that will protect the navigable waters of the country from pollution; that they should suggest to other departments of the government that they themselves observe and enforce sanitary measures in this regard.

ACTION OF STATE AUTHORITIES

The principal oyster growing states along the Atlantic coast are giving or are preparing to give active attention to the protection of shellfish. The final solution of the problem has not been

reached. In a paper before the American Medical Association in 1910 Prof. C. A. Fuller summarizes well the situation. We quote the last paragraph of his paper with an addendum as published in the *Journal of the Association*, March 11, 1911, as follows:

The period is distinctly constructive in tendency. Much work on the problem of shellfish pollution is now in progress in American laboratories. Massachusetts and Virginia have been most active and apparently have the problem well in hand. New York has made a preliminary survey of its oyster-grounds, but the department of health does not feel that it has done sufficient work to warrant the fixing of definite standards of shellfish pollution. New Jersey is now taking active measures to control the hygienic condition of its large shellfish areas. The shellfish commission of Rhode Island is now making a very comprehensive survey of the waters of the state. Connecticut is about to commence a sanitary survey which will cover all the tidal waters of the state. The Maryland Health Department is examining bacteriologically various samples of market oysters but have formulated no standards of pollution. The present year will unquestionably be productive of important results which will add to the knowledge of the problem of shellfish pollution and aid in formulating a more accurate and safer standard of pollution.

Since the preparation of the above paper, the results of several laboratories, which have been engaged on oyster work during the past year, have been presented at the meeting of the American Public Health Association. The situation was carefully gone over and proposed standards of purity discussed. Among the more prominent of these was that recommended by the United States Bureau of Chemistry which has in charge the bacteriological examination of oysters and other shellfish for pollution under the food and drug acts of 1909–1910. This standard condemns all oysters in the shell which "show the presence of *B. coli* types of organisms when present in three out of five oysters in 0.1 cubic centimeter of the shell liquor." These examinations are supplemented by an inspection of the beds from which the oysters were obtained, also by the bacteriologic examination of the water bathing the oysters from these localities. The government has prevented the shipment and sale of several lots of these shellfish which have not come up to the standard.

The survey of the oyster-grounds of Rhode Island has also been completed. The state shellfish commission has used the federal standard of purity in interpreting the results of bacteriologic analysis and has condemned and refused certificates of inspection to more than half the oyster-grounds of the state, comprising an area of over 3000 acres

of cultivated oyster-grounds. About 25 per cent. of the beds were passed conditionally, subject to later inspection. Official certificates of inspection were issued by the commission only to grounds which came up to the federal standard of purity.

While a number of bacteriologists have employed the standard of the federal government in judging the sanitary condition of oysters, the general opinion of the American Public Health Association seems to be that it is too high. The committee on standard methods of analysis failed to recommend a definite standard of purity for shellfish analysis since they felt that further investigation of the problem must be carried on before they were warranted in adopting any definite standard. The federal standard is a tentative one and "as yet there are no established standards for the bacteriologic examination of shellfish."

REPORT OF COMMITTEE OF AMERICAN PUBLIC HEALTH ASSOCIATION

This Committee is composed of Messrs. George C. Whipple, Chairman, A. W. Freeman, Stephen De M. Gage, William Royal Stokes, H. D. Pease, Secretary.

In September, 1910, at the Milwaukee meeting of the Association, it made an important preliminary report as to the technical aspects of the question of standard methods of shellfish examination. The report is printed in the *Journal of the Association* for August, 1911.

At the Havana meeting in December, 1911, the Committee made a further report in which they made certain modifications of the previous schedule. It is understood that this was endorsed by the laboratory section of the Association at the Havana meeting. Some supplementary tests are mentioned which we will not now attempt to detail.

The report seems to be carefully considered, indicating a fair-minded viewpoint and a serious desire to secure cooperation between the shellfish growers and those having in hand the interests of the public health.

Interpretation of Results.—The committee states that it does not feel called upon to establish at the present time any standards of purity. This matter should be determined, according to the Committee, by the various administrative authorities interested in the subject.

Importance of Inspection.—The Committee recognizes that by analysis alone the hygienic character of oyster beds cannot always be satisfactorily established. The beds and their surroundings

should be carefully inspected, and this is just as important as examination of the shellfish and the water surrounding them.

A satisfactory method of scoring the hygienic standing of oysters has received careful attention by the Committee, and a tentative score card has been prepared. The Committee hopes to be able at the end of another year to suggest a score card for general adoption.

LEGAL DECISIONS REGARDING OYSTER POLLUTION

In England, several decisions have been handed down in this matter. They are perhaps so closely identified with local laws that their significance for American conditions is not so great as might appear at first glance. However, a few summarized decisions are quoted from the law notes of the "Surveyor" and from the "Public Health," each of London, in order to record the outcome of some of the epidemics noted in the early pages of this chapter.

Sewage Disposal: *Pollution of Oyster Beds.*—The decision of Mr. Justice Walton in Foster v. Warrington Urban District Council (noted at page 257 of Vol. XXVII) has been affirmed by the Court of Appeals (Lords Justices Vaughan Williams, Sterling and Fletcher Moulton, April 3). The plaintiff, J. Duncan Foster, owner of the principal oyster business at Emsworth, near Chichester, sought an injunction to restrain the defendants from placing or maintaining their sewer outfalls in the neighborhood of his oyster storage beds on the foreshore of Emsworth Creek, so as to contaminate the beds and to render the oysters liable to become infected and unsafe for human food and to cause a nuisance to him. He also claimed damages for loss and injury to his business. Mr. Justice Walton gave judgment for the plaintiff for damages, to be ascertained. The appeal was dismissed. Lord Justice Vaughan Williams, in giving judgment, said there could be no doubt that the plaintiff's oysters were contaminated by the discharge of sewage. There was really no dispute about that at all, because some of the oysters were eaten at a banquet at Winchester, with the most lamentable results. After stating the facts of the case, his lordship said he was of opinion that the defendants were liable in damages to the plaintiff, and that the decision of Mr. Justice Walton was right, and that the appeal should be dismissed with costs. The other lords justices concurred.

This case came on again before Mr. Justice Walton for further hearing to assess the damages (King's Bench Division, May 15). It will be remembered that the object of the action was to obtain an injunction restraining the council from maintaining their sewer outfalls in the neighborhood of the plaintiff's oyster storage-beds on the foreshore of Emsworth Creek, and from discharging sewage there so as to contaminate

the oysters. The plaintiff further claimed damages for loss and injury to his business. The evidence showed that certain persons present at a banquet at Winchester, held in November, 1902, died from typhoid, caused (according to the conclusion of the Local Government Board after an inquiry) by eating oysters from the plaintiff's beds. Mr. Justice Walton gave judgment for the plaintiff, and the Court of Appeal affirmed his decision. At the present hearing his lordship, in giving judgment, said that the plaintiff had been deprived of the use of the oyster-beds from December, 1902. He had also suffered damage in consequence of the removal of his oysters from Emsworth to Hayling, as well as from mortality of the oysters. There was also some disturbance to his business in consequence of its removal. It was very difficult to form an estimate, but the plaintiff was entitled to some damage under all the above heads. But he made a much more serious claim. He said that in 1902 the public became scared in connection with the contamination of the Emsworth beds, and that he suffered a loss of business, for which he claimed some £10,000. His lordship did not think the plaintiff could recover for general depression of the oyster trade. It was not strictly caused by any act of the defendants. In 1902 he was selling the oysters with the knowledge that they might be contaminated. He must bear the loss caused by the general depression of the market. But for the particular loss arising under the heads already mentioned he awarded him £850.

Nuisance. Pollution of Oyster Bed by Sewage. Right of Local Authority to Discharge Sewage into the Sea[1]

A local authority has no right at common law or by statute to discharg. sewage into the sea in such a way as to cause a nuisance to oyster beds formine part of an ancient fishery and if pollution is so caused the authority will bg liable to pay damages for the injury caused and to be restrained by injunctione

This was an action for an injunction and damages in respect of an alleged pollution of the plaintiff's oyster beds in Hadleigh Bay, near Southend, by sewage coming from the outfalls of the defendant corporation's sewage system. The case lasted nine days, and on February 21, 1906, J. Buckley, delivered a considered judgment in which the facts are set out.

J. Buckley, in the course of his judgment, said: The plaintiff is lessee in occupation of a certain part of an ancient several fishery, being oyster-beds situated in the creek or gut called Hadleigh Bay, in the estuary of the Thames, some three miles and a half above Southend Pier. The defendants are the Corporation of Southend. They discharge the sewage of Southend in a crude state, without any treatment,

[1] From Public Health, London, May 1906, and quoted in 1906 report of New Jersey State Board of Health.

into the estuary at several outfalls, of which the main outfall lies some 500 or 600 yd. east of Southend Pier, and the others lie in various positions, principally on the west side. The plaintiff's action is for an injunction to restrain the Corporation from so discharging sewage as to create a nuisance to him by the pollution of his oyster-beds, and for damages. The question which I have to try is the issue of fact, whether the discharge from the defendants' sewers does or does not create a legal nuisance to the plaintiff's oyster-beds. The defendants have raised a certain other defense as matter of law. With that I will deal separately. That there is pollution at the site of the plaintiff's oyster-beds is not denied. The question is whether it is due to the defendant's sewers. * * * The plaintiff is entitled to the enjoyment of a several fishery; he has the right to enjoy the land for the purpose of laying oysters there. That right of his in the land is interfered with by nuisance caused by the discharge by the defendants from their pipes of offensive matter in such a way as that it reaches the plaintiff's land. Upon the principle of "Fletcher v. Rylands" (L. R. 1. Ex. 265; 3 H. L. 330), and the decisions upon which that case was founded, the defendants must keep their noxious matter from trespassing upon their neighbor's land. "Tenant v. Goldwin" (1 Salk. 21,360; 2 Ld. Raymond 1,089) is an express authority upon this point. They have, I think, no common law right. But, if there be no right at law, there is a right, say the defendants, by statute. For that purpose they refer to Section 49 of 11 and 12 Vict., c. 63 (the Public Health act, 1848), and argue that, inasmuch as if the sea be within 100 ft. of the site of a house the owner might under that act have been called upon to construct a drain into the sea, there must be a right to drain into the sea. The act of 1848, however, was repealed by the Public Health act of 1875, and Section 23 of the latter act, in reproducing the substance of Section 49 of the former, omits all provision as to draining into the sea, while Section 27 of the act of 1875 provides that, for the purpose of disposing of sewage, the local authority may do certain things, but with this proviso, that no nuisance be created in the exercise of any of those powers. Any argument based upon the repealed act of 1848 seems to me, therefore, to be displaced. But the matter does not rest there. By the Sea Fisheries act, 1868 (31 and 32 Vict., c. 45), the property in oysters and mussels is, by Section 51, in the owner of the fishery, and by Section 53 it is not lawful for any person, other than the grantee, within the limits of a fishery, knowingly to disturb or injure in any manner any oyster-bed, and a penalty is imposed for doing the forbidden act. Further, by the Sea Fisheries act, 1888 (50 and 51, Vict., c. 54), provision is made for the creation by the board of trade of sea fishery districts, and for local fishery committees for the regulation of sea fisheries carried on within the district. It is provided by Section 2 that a local fisheries committee may, with the confirmation of the board of trade, make by-

laws, among other things, prohibiting or regulating the deposit or discharge of any solid or liquid substance detrimental to sea fish or sea fishing. The plaintiff's fishery lies in the Kent and Essex Sea Fisheries District, and within the jurisdiction of the Kent and Essex Sea Fisheries Committee, being a district and a committee constituted under that Act of Parliament. They have made by-laws which have been properly confirmed by the board of trade, and by-law 15 provides as follows: "The deposit or discharge of any solid or liquid substance detrimental to sea fish or sea fishing is hereby prohibited." Not only, therefore, have the defendants no common law or statutory right to discharge the sewage so as to cause a nuisance—they are, in my opinion, forbidden to do so by a by-law properly made under a statute. This by-law is binding upon the defendants. They have no power to discharge sewage given them by a general or local Act of parliament or by a provisional order confirmed by Parliament. In my judgment, the plaintiff has proved a nuisance against which he is entitled to an injunction, and I grant an injunction to restrain the defendants as asked in the claim, limiting it in point of time to the duration of the plaintiff's lease. The plaintiff also claims damages. I assess them at £1500. I give judgment, therefore, for £1500 damages, an injunction in the terms I have stated, and for the costs of the action, the costs being on the higher scale.

In commenting upon the foregoing case a writer in the Sanitary Record (May 31, 1906) says:

Oyster-beds and their pollution by sewage are matters which must have exercised the minds of local authorities in more places than Southend-on-Sea. Nevertheless, the case of Hebont v. Southend Corporation (reported *Law Journal*, March 3, 1906, page 141) raised issues which will dispel their doubts on many points of law. The plaintiff was lessee of oyster-beds which were part of an ancient several fishery. The defendants raised an issue of fact, namely, that the pollution did not arise from their sewage. They also raised certain legal defenses: (1) Their common law right to discharge sewage into the sea; (2) they claimed a statutory right, since Section 49 of the Public Health act, 1848 (11 and 12 Vict., c. 63, Sec. 49) requires that a house within 100 yards of the sea should be drained into it, if the local authority directs, the section impliedly admitting the right to drain into the sea. Mr. Justice Buckley, however, granted an injunction against the corporation limited to the duration of the plaintiff's lease, and assessed the damages at £1500. In the course of his judgment he held that on the evidence it had been established that the pollution of the oyster-beds had arisen from the corporation sewage; that the defendants had no common law rights to discharge their sewage upon the oyster-beds belonging to the

plaintiff, nor had they any such statutory rights as had been claimed, since Section 49 of the Public Health act had been repealed, no mention being made in Section 23 of the Public Health act, 1875 (38 and 39, Vict., c. 55), Section 27 expressly enacting that no nuisance shall be created in the disposal of sewage. On other grounds the learned judge also decided against the corporation. For many reasons the judgment of Mr. Justice Buckley will be welcomed, but possibly most by the eaters of the oyster. Typhoid in the future, if proper measures are taken to prevent the contamination of the oyster by sewage matter, is likely to be forgotten as associated with oysters.

RÉSUMÉ

Shellfish taken from sewage-polluted water are liable to transmit water-borne diseases the germs of which are not completely killed by the ordinary method of cooking oysters and clams. Evidence is not well crystallized as to the extent to which typhoid fever and other intestinal diseases are so transmitted. Apparently the danger is less in winter than in warm weather. Epidemics of great extent have not occurred.

States along the Altantic coast have in some instances prohibited the sale of shellfish from certain polluted sources. Some states are beginning to issue certificates for shellfish layings in satisfactory sanitary condition. There are no commonly accepted standards by which to judge the shellfish layings, and much uncertainty obtains relative to beds that are not above suspicion but which are not grossly polluted.

Oystermen seem to feel that the sanitary significance of shellfish pollution has been overestimated, but they realize the importance of meeting reasonable requirements in the interests of the public health. Apparently they would welcome certificates as to proper sanitary condition of their oyster farms and shipping establishments. They resent, however, the efforts of the United States Board of Food and Drug Inspection to prohibit the floating of oysters in waters of less salinity than that in which the shellfish were grown. Testimony on this score is now being taken at Washington.

The period is a transitional one, giving promise at an early date of affording greater and needed protection both to the grower and consumer of shellfish.

What the legal significance may be of the pollution of private layings is a question upon which there is almost no evidence in America.

CHAPTER VI

THE PROBLEM OF SEWAGE DISPOSAL

Sewage disposal deals essentially with the elimination of nuisances coming from household and trade wastes which are removed by water carriage. There are two principal nuisances which are conspicuously due to sewage. The first is caused by conditions that are offensive to the senses of sight and smell. The second class of nuisance is associated with the disease germs contained in sewage and which are transmitted to neighboring communities through the water of the stream into which the sewage is discharged or through shellfish.

The disposal of sewage or the sanitary wastes of a community should be such that no nuisance will arise therefrom, that no injury will be done to persons or property, and that the cost of the disposal to accomplish the desired ends will be as low as practicable for a term of years. Major fish life needs reasonable protection, although evidence is inconclusive as to what this signifies.

For new sewerage systems, built where sewage purification is required, the so-called "separate" system of sewers is adopted. They deal with household wastes exclusively, so far as that is possible. The so-called "combined" sewers, taking also storm water and street wash, are not so generally used on new projects as formerly, because where sewage purification is involved the economical merits of the combined system are far less pronounced than where sewage purification is not a factor. In fact, in a number of instances, American cities are rebuilding or planning to rebuild their combined sewerage systems so as to provide separate pipes for the removal of household wastes.

WIDE RANGES IN CONDITIONS MET

In the case of most professional work, there is an individuality which has to be reckoned with seriously in the solution of each problem. This is true of the work of the surgeon, the lawyer, the railroad engineer, the mining engineer, etc.; but with none is

the variation in the condition of local problems more conspicuous than in the field of sewage disposal.

There are, of course, important features in common in the solution of various projects, but, generally speaking, there are also characteristics of each plan which show or ought to show the adjustment of the design to the particular conditions surrounding it. Even as to the degree of purification obtained or needed to be obtained, there are wide differences which sometimes have not been recognized, but the importance of which is becoming more and more appreciated. Obviously the projects should meet the requirements of the statutes applicable to each case. These laws vary widely in the different states, change frequently in some states and are practically absent in other states. The common law is also interpreted variously as to what constitutes a nuisance, and the same is true of what constitutes a "reasonable use" of a stream or body of water by a riparian owner. A stringent viewpoint prevailed in the case of the Commonwealth of Pennsylvania *vs.* Soulas and others, decided in 1884, with respect to the pollution of the Schuykill river and quoted at length by Messrs. Rafter and Baker in "Sewage Disposal in the United States," pages 98–9. A correspondingly lenient viewpoint was taken by the court in a recent decision in the pollution of the Grand river by the city of Grand Rapids, Mich., mentioned in the *Municipal Journal and Engineer* for Sept. 14, 1911. An interesting discussion upon "The Pollution of Waters at Common Law and Under Statutes," by Hon. Chas. F. Choate, Jr., is found in the *Journal of the Association of Engineering Societies*, 1908, Vol. XL, page 53.

Bearing in mind that the elimination of nuisances is the object of sewage disposal and that it goes without saying that this should be done as economically as practicable, it will be well to outline briefly a series of problems of various types so that there may be better realized the necessity of adjusting to local conditions in the premises. Half a dozen types or so may be illustrated by brief reference to several actual projects.

Type A, New Orleans, La.—The new sewerage system of the city of New Orleans, built on the separate plan, provides for the discharge of the sewage after screening into the Mississippi River, well beneath the water surface and at a point where eddies and currents do not carry the discharge ashore. The well dispersed sewage in the current of this enormous river is carried to sea with-

out any resulting nuisance. It flows for a hundred miles or so mingled with the water of the river, which is highly charged with mud, to the jetties at the river's mouth; and during this travel does not affect the water so that it cannot be used after proper clarification for a domestic water supply. As a matter of fact, however, there are no communities below New Orleans using the river water, which at times is brackish, and there are no shellfish to be contaminated.

Natural agencies effect a far greater purification of polluted river waters, both as regards the reduction of organic matter and also the dying off of bacteria, than is frequently supposed to be the case. Indeed there is no place where this is more strikingly demonstrated than at New Orleans, where extensive investigations were made in 1900–01 in connection with the water purification project recently put in service there. Numerous carefully conducted analyses show that the water of the Mississippi river at New Orleans contains comparatively little or no trace of sewage pollution, although this river receives the sewage of an urban population of more than 9,000,000 people. A fact of much bearing upon this result is that very little pollution reaches the Mississippi river during the last 600 miles of its flow above New Orleans, as the drainage of the "delta" country is away from and not into the river. The mean and minimum stream flows are about 700,000 and 200,000 cubic feet per second, respectively.

Type B, Cologne, Germany.—The city of Cologne, Germany, is situated on the Rhine, and has for years discharged its sewage into the river without substantial purification. This river is much smaller than the lower Mississippi, and the water at some of its mouths is used for drinking purposes, such as at Rotterdam and Schiedam, Holland. A project was at one time considered for the purification of the sewage of this city, but extensive investigations led to the acceptance by the Imperial Board of Health of Germany of the present project, which was put in service a short time ago. These works comprise very fine screens by which the coarse suspended matters are removed, a small sedimentation basin in which are removed those matters which might produce sludge banks in the river, and in which basin it is stipulated that the sewage shall be thoroughly disinfected upon such occasions as the Imperial Board of Health authorities may designate. These periods obviously relate to times of local epidemics of communi-

cable diseases, the germs of which are water-borne. It is believed that this proposition is a fair and reasonable one; but to appreciate fully its significance it is necessary to bear in mind two things. The first is that the Germans are more insistent than are the authorities in this country as regards rigid disinfection, which should be practised at the bedside of all suffering from infectious water-borne diseases. The second is that the water supplies taken from the lower Rhine are thoroughly filtered, as is well proved by the low typhoid fever death rates enjoyed in the past by the city of Rotterdam. More will be said below on the question of the relation between sewage purification and water purification.

The small town of Red Bank, N. J., offers in some measure an analogous set of conditions to that of Cologne, in that the sewage is first treated in a large settling tank, usually operated on the septic principle, and the effluent of which is more or less regularly disinfected with chloride of lime to guard against pollution of the shellfish in the neighboring waters into which the effluent flows. Similar projects have been recommended by the author for the treatment of the sewages of New Brunswick and Riverton, N. J., with the sewage first treated by fine screens or Imhoff tanks.

Type C, Columbus, Ohio.—At Columbus sewage purification works were put in service late in the autumn of 1908, the purpose of which is to prevent offensive putrefaction in the river. The removal of bacteria is accomplished to a substantial degree, but this is an entirely incidental feature to the process which produces the result above stated.

To appreciate these local conditions it may be stated that the Scioto river during protracted droughts contains but a very small volume of water and the large storage reservoir recently completed above the city of Columbus will doubtless lessen these dry weather flows in the future. Below Columbus on the Scioto river there are no communities deriving water from this stream during its flow of about 100 miles to its junction with the Ohio river. From the mouth of the Scioto to the intake of the Cincinnati water works is approximately another 100 miles, making a total flow of 200 miles for the effluent of the Columbus sewage purification works before reaching a public water supply.

Another illustration of this type of sewage purification problem where the elimination of nuisances to the senses is necessary is

that of the project recommended by the author in 1908 at El Paso, Texas, where the effluent will discharge into the Rio Grande, the flow of which is almost nominal at the end of their protracted dry seasons and which it is expected will become actually nil for months at a time upon completion by the United States Reclamation Service of the large Engle dam to store for purposes of irrigation practically all of the stream flow of this river.

Type D, Reading, Pa.—This city is located on the Schuylkill river some 60 miles above the city of Philadelphia which draws a portion of its water supply from this river and subjects it to efficient filtration. The removal of objectionable suspended matters and of decomposable organic matters is not considered in the same light here as in the instances last cited. Bacterial removal to a certain extent is here important so far as relates to diseases-producing germs.

Type E, Montefiore Home, Bedford Station, N. Y.—The sewage of this institution is very thoroughly purified by filtration through land, following a preliminary treatment by sedimentation and sprinkling filters. The effluent enters Croton lake, the source of the unfiltered water supply of New York City. A larger plant in the same neighborhood and for the same purpose has been built for the village of Mount Kisco, N. Y.

Type F, Baltimore, Md.—The sewage at Baltimore is purified by sedimentation and sprinkling filters, and consideration has been given to a finishing treatment comprising either intermittent sand filters operated at a fairly high rate, or the sterilization of the sprinkling filter effluent by some germicide. The purpose of this is to meet certain legislative requirements, in order to protect the extensive shellfish layings in Chesapeake bay within a comparatively short distance of the city of Baltimore.

ECONOMICAL ASPECTS OF PROBLEMS

Enough has been said above, it is believed, to make it plain that there are different types of problems which can be solved by different types of treatment in order to meet thoroughly all reasonable sanitary requirements. There are few if any sanitary authorities of importance in the world who do not recognize this fact, which makes the design of sewage disposal projects a somewhat different proposition in various communities. In this

country a large number of state departments of health approve of reasonable plans with the proper stipulation, in the opinion of the author, that the works shall be built and operated so as to produce an adequate degree of purification and that the authorities reserve the right to call for modifications and improvements when such are found necessary.

There has been some argument in some quarters in favor of a uniform degree of purification to be effected by various local authorities, but it is believed by the author that the sanitary requirements at least of the present day do not require such. The above outline as to different types of sewage disposal conditions clearly accentuates the thought that some communities have certain decided advantages over others as regards their location in the matter of necessity for sewage purification. Such advantages of location obviously exist with reference to water supply, collection of sewage with or without pumping, and various other branches of municipal development.

The general policy of the European authorities who have made the most progress along sanitary lines seems to be to insist first and uniformly upon the elimination of gross nuisances and then to proceed to a plane of excellence as regards the refinements at a time when and along such lines as each local community demands.

The author is in sympathy with that viewpoint, believing that it will accomplish the greatest amount of good from the sanitary standpoint and that it will allow, as a general proposition, economical arrangements which will be beneficial and wise.

To insist upon sewage purification to a high degree for each community in a valley before insisting upon the correction of polluted water supplies seems to be folly. The broad sanitary requirements of communities should be carefully considered and money spent in a way that will produce the most good.

RELATION TO PUBLIC WATER SUPPLIES

There are three main aspects of sewage disposal in its relation to public water supplies, as follows:

1. The treatment of sewage to the extent of preventing nuisances and gross injury to fish life, with the thorough filtration of the public water supply drawn from the stream into which the sewage effluent is discharged.

2. The thorough purification of all sewage where the effluent is discharged into a water supply which goes to consumers without filtration, and which is assumed either to be practically pure before the sewage effluent reaches it, or else to have been greatly improved by subsequent storage and sedimentation.

3. This deals solely with the extreme problems which call for a thorough purification both of the sewage and of the water drawn from the stream into which the purified sewage passes.

In this connection it is well to bear in mind that the relative economy of different treatments is an important proposition and that sanitary scientists stoutly insist upon surface water supplies being filtered before use as a general proposition. In Germany practically all surface water supplies are required to be filtered and the same is practically true of Great Britain. The wonderful progress made in water purification in this country during the past dozen years shows that the foremost American States and cities are following closely the standards set up by European authorities. There are, of course, some exceptions to the rule, but, generally speaking, it is believed that sanitary authorities should recognize the necessity of filtering practically all surface water supplies and that sewage purification to the extent of preventing nuisances should ordinarily suffice for sewage effluents entering the sources of water supply.

In this particular, as will be shown later on, it is to be stated that there is a considerable removal of bacteria in reliable processes for securing the elimination of nuisances from excessive amounts of organic matter in ordinary sewage.

It is also to be noted that it is the general custom in this country where feasible to secure water supplies from as good sources as possible. In some of the cases forming exceptions to this custom, the conditions are of such nature that the elimination of disease germs to the highest practicable degree from sewage is very desirable. There are still other watersheds where thorough purification is required both of the water and of the sewage.

The author's views on this general proposition are in accord with the statements in a report (1908) of the Royal Commission on Sewage Disposal of Great Britain, as follows:

> We are satisfied that rivers generally, those traversing agricultural as well as those draining manufacturing or urban areas, are necessarily exposed to other pollutions besides sewage, and it appears to us, there-

fore, that any authority taking water from such rivers for the purpose of water supply must be held to be aware of the risks to which the water is exposed, and that it should be regarded as part of the duty of that authority, systematically and thoroughly, to purify the water before distributing it to their customers.

Apart from the question of drinking waters, we find no evidence to show that the mere presence of organisms of a noxious character in a river constitutes a danger to public health or destroys the amenities of the river. Generally speaking, therefore, we do not consider that in the present state of knowledge, we should be justified in recommending that it should be the duty of a local authority to treat its sewage so that it should be bacteriologically pure.

The reasonableness of this position becomes the stronger when one realizes that many water supplies need filtering to make them "clean," as regards turbidity and vegetable stain; and, further, that waters can be practically sterilized by the hypochlorite or oxychloride treatment at an almost nominal cost according to recent experiences with the Jersey City supply at Boonton, N. J.

RELATION TO SHELLFISH

Reference has been made already to the unusual problem existing at Baltimore, where the extensive oyster layings in the Chesapeake bay prompted the Legislature of Maryland to call for a very thorough purification of the city's sewage. The individuality of the local conditions as regards this aspect of the problem is of much significance, and it is hardly feasible to lay down hard and fast rules.

Speaking generally, it seems apparent that where small sewage disposal projects are associated with large shellfish industries the latter, as a business proposition, should not be injured or destroyed when a relatively small sum of money will produce a satisfactory purification of the sewage. On the other hand, where the question involves a very large center of population, with its corresponding cost for sewage purification beyond the point of preventing gross nuisances, then it seems that the small shellfish industry should become subservient to the larger public interest, and should be abolished after receiving such compensation as it may be legally entitled to. Where the relative money values of the shellfish industry and of the associated sewage disposal proj-

ect approximate each other, it becomes a matter for careful consideration and equitable adjustment for each locality.

POLLUTION LAWS

Those communities having soon to build sewage disposal works obviously are entitled to know as soon as practicable what will be the definite attitude of the State authorities as to their particular project.

Perhaps further reference should be made to the laws of the different states as to sewage disposal, because they vary so widely. It is considered sufficient for present purposes, however, to call attention to Water Supply Paper 103, published in 1904 by the U. S. Geological Survey, a "Review of the Laws Forbidding Pollution of Inland Waters in the United States," by Mr. E. B. Goodell. An important duty of those having sewage disposal projects in hand is to ascertain definitely what the laws require them to provide.

The United States Government at present has no control over sewage disposal except insofar as sewage deposits relate to the shoaling of navigable bodies of water. (See Act approved Mar. 3, 1899, in the Supplement to the Revised Statutes of the United States, Vol. II, page 994.)

The above synopsis of the sewage disposal problem is taken with few modifications from a lecture delivered by the author on the "Principles of Sewage Purification," at Cornell University in May, 1909. Undoubtedly it could be much elaborated as to details. It is believed, however, that sufficient has been said to indicate the needs of the problem and the variations in its solution, so that the reader may grasp the descriptions and discussions of the actual accomplishments of various methods of disposal, as set forth in the following chapters.

A sense of proportion is greatly needed now not only in the solution of sewage disposal problems, but also in their consideration with respect to other sanitary questions.

CHAPTER VII

EXPERIMENTAL METHODS AS APPLIED TO SEWAGE DISPOSAL PROBLEMS

That progress means advance in knowledge and the gradual transition of information from the unknown to the known is of course a truism. The manner by which progress is made in different lines of work varies widely. The experimental method as applied to the teaching of science in educational institutions has been of great benefit, and the application in a more systematic manner than formerly of the so-called "cut and try" method of the early inventors has resulted in more substantial progress in many mechanical and industrial lines. By the man of affairs this advance in knowledge is referred to as additional experience. It is not the purpose here to attempt an analysis of the manner by which knowledge in general is advanced, but to refer somewhat briefly as a matter of record to the way in which there have been solved various sanitary problems which a generation ago, for financial or other reasons, seemed out of question.

While the experimental method so successfully applied in the student laboratory may in its way call for just as conscientious and diligent effort as when applied to projects involving immense sums of money, yet the responsibility associated with the latter is far greater. It is necessary, in carrying out successfully these large practical problems, not only to draw correct conclusions from full representative premises of a complicated nature, but also to adjust the project to a reasonable business basis, to make it fairly well understood by non-technical officials and citizens, and to defend it from the obstructionists who, for political or selfish reasons, cross the pathway of nearly every large public enterprise. In meeting these requirements there has been called forth a series of efforts which are of great significance to the public from the sanitary and financial standpoints, and which form notable achievements in the field of applied science.

Much of the material of this chapter was prepared for a paper in the "Sedgwick Quarter Century Book," after the author had carefully weighed the accomplishments in sanitary science of the

Massachusetts State Board of Health and the Massachusetts Institute of Technology, institutions which Prof. W. T. Sedgwick has served many years as investigator and teacher.

BENEFITS OF IMPROVED SANITARY WORKS

Improved water and sewage works of course do not explain by any means the entire improvements which for the past quarter of a century have been so characteristic of the sanitary conditions of a majority of the civilized communities of the world. But, illustrative of the scope of such improvements under the guidance of wise sanitary authorities, it is of interest to point out the markedly decreased death rates in Massachusetts from water-borne diseases, of which typhoid fever is the typical, but not the only, one.

TABLE 39.—AVERAGE ANNUAL DEATH RATES PER 100,000 POPULATION FROM TYPHOID FEVER IN THE STATE OF MASSACHUSETTS BY FIVE-YEAR PERIODS FROM 1881 TO 1910

Period	Rate	Period	Rate
1881–1885	41	1896–1900	26
1886–1890	46	1901–1905	19
1891–1895	34	1906–1910	14

What is true of Massachusetts is in a general way true of many sections of both America and Europe where the population has become quite dense, and demands for water and sewage works of satisfactory character have pressed forward for attention in recent years. No attempt will be made here to show the great sanitary benefit derived from other factors than improved water supply and sewerage, as this matter is clearly set forth in standard works upon sanitation and official reports from various quarters of health authorities who deal with the accomplishments of the modern health officers.

It is sufficient here to present clearly to the reader the thought that modern sanitary science has greatly increased the comfort and safety of living. In various cities the reductions in death rates have been far greater than as given above for the State of Massachusetts. This is especially true in cities where badly polluted water supplies have been replaced by improved supplies. Numerous instances of this sort are on record where annual typhoid fever deaths of 50 to 100 per 100,000 have been reduced to about 20 or less. These cities include not only those now

receiving upland waters from unpolluted sources, and ground water, but also those having filtered water from earlier but polluted sources. Intestinal diseases other than typhoid fever have been so reduced as to lower the general death rate materially. For low-lying communities like New Orleans modern drainage has lessened notably the general death rate, and sewerage brings safety as well as comfort to communities, among other ways by eliminating privy vaults and the likelihood of disease transmission by flies, etc.

NEW CONDITIONS WHICH HAVE BEEN ENCOUNTERED

A generation ago the large cities of America were, of course, provided with public water supplies, and many of them had progressed considerably in adopting sewerage systems, although these latter now appear to have been more or less crude. Sewage purification plants and water purification plants, with perhaps half a dozen small and scattered exceptions, were practically unknown. A large proportion of the water supplies, especially in the Central West, were seriously objectionable in the excessive quantities of mud which they carried, and so different in their nature from the comparatively simple filtration projects of Europe that engineers naturally hesitated for financial reasons to attempt their construction, to say nothing of the question of whether they would be able to give satifactory service. The bacterial and hygienic aspects of these problems, which are now recognized to be of so much importance, were almost unknown. In fact, the germ theory of disease had not risen to general acceptance.

The medical man interested in public health knew in a general theoretical way what he wanted, but he was ordinarily unable to state his requirements in a manner understood by the engineer or by the taxpayer. Engineers were able to build any reasonable works, but were unable to learn in terms of the constructor what was required with sufficient definiteness to allow them to make even preliminary sketches and estimates of cost. The chemist and bacteriologist occupying an intermediate position produced with ill-suited methods analytical data full of mystery for everybody.

Misunderstanding continued until men interested in various lines of applied sanitary science cooperated in a manner to make themselves mutually understood. The successful movement to this end, at least in the United States, had its inception chiefly in Massachusetts some years ago. It has resulted during the past

dozen years in some well-balanced designs for American water and sewage works, which have demonstrated their sound merit in practice. It is the endeavor here to outline the development of this aspect of experimental methods as applied to sewage works and incidentally to water problems.

EXPERIMENTAL METHODS IN MASSACHUSETTS

The experimental methods which have been put in practice in America so frequently in recent years may be defined as the bringing together of reliable preliminary data from the engineering, chemical, bacterial and hygienic standpoints, in order that efficient sanitary works may be built for a wide range of local conditions within the limits of reasonable cost; and if data are inadequate for fair assumptions, then the procuring of the needed data by practical tests on a small scale.

It is the Massachusetts State Board of Health to which credit is principally due for developing this method to serve as a guide for such works. In 1886, when the present Board was organized, one of its first steps was to establish the Lawrence Experiment Station, whereby data were to be secured to show the best means available under various local conditions for purifying water and sewage. The Legislature enacted that this Board should serve as a sanitary tribunal, before which the local authorities should place their projects for water and sewage works, and whose approval was requisite before the State Legislature granted the local authorities permission to issue bonds for their construction. This experiment station (see Fig. 1) has been in continuous service since the autumn of 1887 under the direction of the distinguished hydraulic and sanitary engineer, Mr. Hiram F. Mills. It has attained a high reputation among various workers in the field of sanitary science throughout the world, in addition to serving its main purpose of aiding the citizens of Massachusetts in economically improving their public works, whereby to a material degree the health and comfort of the people of the state have been enhanced. These results are so well known that it is needless to go into detail. It is sufficient here to refer to the excellent summary of the entire work up to the end of 1908, appearing in the report for that year, and to which frequent reference will be made.

The classical investigations at Lawrence, as set forth in the annual reports for the past 20 years, have undoubtedly done more than any other series of investigations in the world to place the

science of purifying sewage on a sound practical basis. It is true that earlier workers abroad had previously taken important steps along some of these lines. But they did not secure comparable parallel data from the engineering, chemical, and bacterial standpoints with anything like the completeness obtained at Lawrence, with the aid of Profs. T. M. Drown and W. T. Sedgwick during the early years, whereby laws governing successful practice could be broadly stated for a wide range of conditions.

FIG. 1.—Lawrence experiment station.

Not only has the Massachusetts State Board of Health availed itself of a testing department, but with other departments it has placed itself in a position to utilize such data advantageously. This has been done by an analytical department procuring data at frequent intervals as to the character of various water supplies, rivers, sewages, sewage effluents, etc., and more especially by a well-trained engineering corps, with Mr. F. P. Stearns up to 1895, and since then with Mr. X. H. Goodnough, as chief, which applies the various local data to the needs of each problem coming to the attention of the board.

That the Massachusetts State Board of Health has handled

well for many years the wide range in work coming within its jurisdiction is conceded by all in a position to know of it intimately. It is true that the Board is criticised for not devoting itself more enthusiastically to studies of methods finding favor elsewhere. This criticism has had little to support it, as a general proposition, as the Board properly confines itself to the solution of problems within the state, and does not consider it necessary to do more than keep generally familiar with other methods, no matter how suitable they may be for work elsewhere. The policy of the Board has been consistently conservative, and lack of speed in adopting the practices of others has showed shortcomings but rarely.

EXPERIMENTAL METHODS ELSEWHERE IN AMERICA

In water purification the Massachusetts problems are, generally speaking, much easier and simpler than those of the Central West and South, where enormous quantities of silt and clay complicate the necessary works for treating the water, and add materially to the cost as regards both construction and operation.

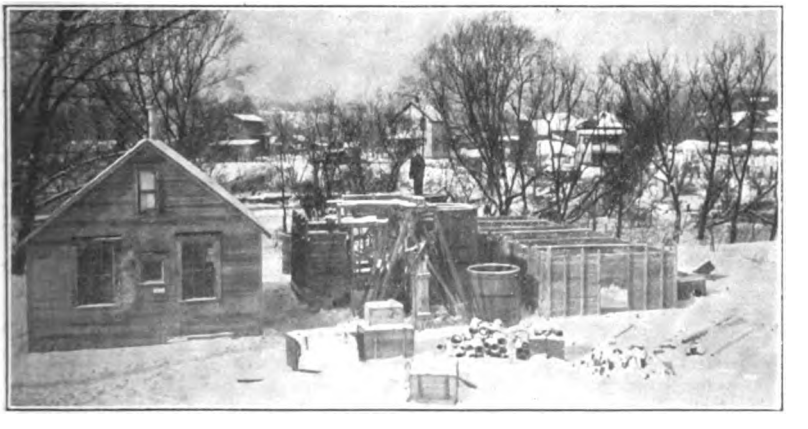


FIG. 2.—Akron testing station.

In a manner similar to the procedure at Lawrence, these problems were worked out at Louisville, Pittsburgh, Cincinnati, New Orleans and elsewhere. At numerous other places the experimental method has been used in adapting more strictly the design of works to local conditions, especially in the preliminary treatment of turbid waters (Philadelphia and Harrisburg), the

removal of color from surface waters (Providence), of iron from ground waters (West Superior), the softening of hard waters (Columbus), and the removal of tastes and odors (Reading and Springfield). These problems have all been carefully studied in small test devices for securing data necessary for advantageous design and operation.

Sewage purification has also been studied under various local conditions at several places, especially at Worcester, Mass.; Pawtucket, R. I.; Berlin, Ont.; the Institute of Technology, Boston; Columbus, Ohio; Waterbury, Conn.; Reading, Pa.; Baltimore, Md.; Gloversville, N. Y.; Philadelphia, Pa.; and Chicago, Ill. In most cases the sewage studies have arisen because of inability or great expense in applying the well-known Massachusetts method of intermittent filtration through sand, or because of peculiarities of the local sewage. The latest testing station to be built is at Akron, Ohio, as shown in Fig. 2, furnished through the kindness of Mr. H. B. Hommon.

A partial list of the more prominent investigations as to purifying water and sewage, with dates and available approximate costs, is as follows:

TABLE 40.—LIST OF SPECIAL AMERICAN INVESTIGATIONS ON WATER AND SEWAGE PURIFICATION

Place	Date	Work	Approximate cost
Lawrence, Mass	1887–11	Water and sewage	$195,000
Providence, R. I	1893–94	Water	5,000
Louisville, Ky	1895–97	Water	47,395
Reading, Pa	1897	Water	1,500
Pittsburgh, Pa	1897–98	Water	36,286
Cincinnati, Ohio	1898–99	Water	41,588
West Superior, Wis	1898–99	Water	2,000
Washington, D. C	1899–1900	Water	8,000
Richmond, Va	1900	Water	2,000
New Orleans, La	1900–01	Water	23,606
Worcester, Mass	1900–11	Sewage	47,500
Philadelphia, Pa	1900–05	Water	172,000
Springfield, Mass	1901–03	Water	18,000
Harrisburg, Pa	1903–04	Water	25,000
Massachusetts Institute of Technology, Boston	1903–11	Sewage	50,000
Columbus, Ohio	1904–05	Sewage and water	44,000
Waterbury, Conn	1905–07	Sewage	14,000
Reading, Pa	1906	Sewage	2,500
Baltimore, Md	1907–08	Sewage	17,500
Oakland, Calif	1907–08	Water	19,390
Gloversville, N. Y	1907–09	Sewage	13,570
Philadelphia, Pa	1908–10	Sewage	24,500
Chicago, Ill	1909–11	Sewage	69,322
		Total	$869,657

It is not pretended that the above list is complete. In fact, there are other tests which, while small and of short duration, have had much to do with professional opinion. Perhaps the most important were demonstrations at Louisville and St. Louis, many years ago, that plain sand filtration was incapable of treating the muddy Ohio and Mississippi river waters after plain sedimentation in large basins.

The benefit derived from the experience of the owners of proprietary devices should not be overlooked—especially in regard various appliances of mechanical filters which occasioned the expenditure of much money before being brought to their present state of development. At Louisville alone the five competing filter companies spent more than $50,000. More recently these devices, when tested, have been purchased at the beginning of the tests.

Mention should be made of the important advances in the allied field of water supply from storage reservoirs, and the disposal of sewage by dilution. Among the more prominent investigations of this kind should be stated the field surveys and laboratory studies made in connection with the Chicago drainage canal, the additional water supply of New York City, the improvement of the Charles, Mystic, and Neponset rivers in Massachusetts, and foreshore pollution along the Massachusetts coast. Several hundred thousands of dollars have been expended on these investigations.

Important tests and inspections are also made from time to time by the state authorities of the more densely populated states, viz.: Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Ohio, Indiana, Illinois, Wisconsin, and Minnesota. The special work of the Ohio State Board of Health during 1906–07 and published in 1908 is especially commendable.

OBJECT AND ADVANTAGES OF EXPERIMENTAL METHODS

The purposes of applying experimental methods to problems of water and sewage purification are chiefly threefold, as follows:

1. To provide data for the official and technical authorities, to enable them to adapt new works most advantageously to the best available method for local conditions, and to indicate dimensions and other physical conditions permitting contract plans to be prepared and the cost of construction to be approxi-

mately estimated. This involves also the improvement of current methods.

2. To educate the non-technical public, who as citizens and taxpayers, are interested in public works.

3. To provide data so that the officials can operate effectively the works after they are completed, and forecast the approximate cost of operation.

Technical Data.—In regard to the first object accomplished, that of enabling city officials and their technical advisers to design economically works of a suitable character, it goes without saying that this has been of the greatest importance. It is a strong factor in explaining the advance in successful sanitary works accomplished during the past few years. It has frequently been the advice of technical men, in dealing with problems which differ from those successfully solved elsewhere, to make tests for a year or so at a cost approximating the interest for one year on the investment for the works contemplated. In this way the cost of errors and unbalanced designs has been reduced and the efficiency has been increased. In the field of water and sewage purification the information and experience now available are sufficient in a majority of particulars to enable these problems to be advantageously handled by experienced workers along these lines. There are some problems, however, that still can be advantageously treated by the experimental method. They refer among others to sewage problems in which trade wastes are involved, and to water problems where the composition of the water is quite unusual in some particulars on frequent occasions. From the technical standpoint, however, the field of water and sewage purification, broadly speaking, has passed beyond the experimental stage, and the advances, both as to efficiency and economy, are largely to be gained, not from experimental plants, but by the more careful and systematic operation of well built works in practice. Such studies will, of course, lead to improvements which can be taken advantage of in the construction of new works, and will gradually bring to a higher plane of excellence the art of water and sewage purification on its present scientific basis. Unfortunately there is usually quite a "lag" in putting into practice the principles representing the best theory on the subject. Just now there is quite a discrepancy between theory and practice as to sewage disposal. In part this involves

questions of public policy and in part it relates to technical matters on which more data are needed.

Educational Aspect.—It is frequently said that communities progress in proportion to the advance in knowledge of the average citizen, or to the mean knowledge of the community as a whole. There is a good deal in this, and it brings forcibly to mind the necessity of educating the public as to what improved sanitary conditions really mean, and of letting them ascertain for themselves what can be accomplished along these lines in the field of applied science. Non-technical people have a natural aversion to the word "experiment," notwithstanding the aid derived from devices which not improperly may be termed experimental. While the term "experiment station" from its use at Lawrence and a few other places seems to have a firm footing in some localities, it is gradually giving place to the term "testing station." This is a much preferable expression in many ways, as it disarms the criticism of many who seem to think that these investigations are conducted in a "hit or miss" manner, much after the fashion of the early inventors. This is not so, as experimental methods, as now ordinarily applied to water and sewage works, are aimed at testing procedures found successful elsewhere, but which may require adaptation to local conditions in regard to some details. Their magnitude, while relatively small for reasons of economy, is still much greater than that which seems to be taken for granted by numerous citizens, who associate the word "experiment" with a test tube, or with a mechanical device which is so imperfect that no one dares to build it on a large scale without further experiments. The methods of purifying water and sewage have now advanced to a degree where the phrase "testing station" in new projects will unquestionably displace "experiment station," and the testing of these processes where unusual conditions are expected will assume a dignity comparable with that of the regular departments which systematically test cement, steel, and other materials used for building purposes. In fact, it is interesting to note that the laboratories at many testing stations have been utilized later and regularly for testing construction materials.

Where water and sewage purification projects involve hundreds of thousands of dollars or more for construction costs, the so-called experimental methods, as applied in accordance with the foregoing statements, have given wonderful courage in many

places to officials who otherwise would very naturally have been in a hesitating frame of mind, and inclined more to listen to the "doubting Thomases" who in all communities, for selfish or other reasons, appear as opponents and obstructionists to modern sanitary works. Even if the technical advisers of the projects were not assisted by such data, it is quite likely that the testing station for many projects would indirectly in this way do far more good than the cost involved, in saving lives and in hastening the day when communities will meet their problems in accordance with the best information available.

In speaking of the educational benefit derived from applying experimental methods to water and sewage works, the technical men, especially those in charge of the tests, have an important duty to perform in teaching non-technical officials, and various citizens who are interested in the work, the fundamental principles of the process involved, and in assisting them in ascertaining what practical works would mean, both hygienically and financially. Along this general line the Massachusetts Institute of Technology has played an important rôle, largely through having had for many years on its teaching staff a man who to an extraordinary degree possesses the faculty of getting fundamental truths of sanitary science before his hearers in such an attractive manner that they never forget them. It is the belief of the author that the work accomplished by Prof. Sedgwick along this line is unequaled by that of any other man in this country, either in educational or other lines, and that this fact in a few years will be far more widely realized than at present, when his younger pupils throughout the country reach an age where their work will be felt in the communities in which they live. This influence is already to be found in many unexpected places, and forms a wonderful tribute to the success accomplished by Prof. Sedgwick in one of his many lines of usefulness.

Operation of Works.—After water and sewage purification works are constructed, it is imperative that they shall be operated in an intelligent and efficient manner. The benefit of this has long been demonstrated in Europe, and the absence of such supervision in many places in America shows the folly of careless and indifferent management. No matter how well water and sewage purification works may be designed and built, there is no engineer who can give assurance that the results accomplished will be satisfactory unless the works are well managed. Not only must

the works produce a result which is satisfactory from a scientific standpoint, but their behavior should be put before the citizens in a way that will inspire confidence. When fair-minded citizens as a mass continue to lack confidence in works of this type, the latter cannot be called an unqualified success, no matter how fully scientific facts may show their adequacy.

It is highly desirable that those responsible for the design and construction of sanitary works should have reasonable authority as well as responsibility with respect to their operation. In several cases the author has been connected with projects solely on the construction of the works, and in other cases only on their operation. This is frequently an unsatisfactory state of affairs, particularly in America, where conditions are complicated by frequent changes in the administrative officers.

The Massachusetts Institute of Technology instituted the plan of especially training young men along technical lines, so that they might become competent to serve as superintendents for water and sewage purification works. In this pioneer work they are entitled to great credit, and their example is already being followed by similar institutions elsewhere. This is an important field of technical education, as a majority of such technically educated men in the future will be connected with the management, rather than with the construction, of works of this type.

In passing, it may not be amiss to say that the technical managers of works of the type under consideration must have other qualifications than those of a scientific nature. They must be able to maintain amicable relations with executive superiors, to manage laborers, to keep records in a manner fairly comparable with the high plane of excellence to which the science and art of bookkeeping in large business houses has advanced, to prepare reports containing essential features in explicit but terse terms, and to make plain to non-technical men in both public and private capacity the more essential features of their own position and of the data by which their efforts show what is being accomplished. This type of specialists will naturally develop in efficiency as their responsibilities increase; but there is still much work for the technical schools to do in preparing young men adequately for these duties.

Tentative Installations.—As distinguished from the testing stations built solely for the purpose of tests, there is, of course,

one other method of a somewhat experimental nature by which local data are used in determining whether large works are most advantageously constructed. Reference is made to the plan of constructing works gradually or tentatively, and of using data from the operation of the first portion of the installation to serve as a guide in arranging the details of the portions subsequently to be built, and also in deciding upon the magnitude of the works sufficient for a given capacity or to serve for a given term of years. This is the style of works, from the experimental point of view, which frequently obtains in Europe, and which will obtain in some places in this country. As yet there has not been a wide application in America of such data obtained on a large practical scale, although, of course, they are availed of more or less in all works where extensions are required. This condition has been reached at several sewage works in New England, and the results of experiences in the field have been summarized by the Massachusetts State Board of Health. It is gratifying to state that practical results are in general conformity with the principles of water and sewage purification as developed by tests on a small scale. There are some exceptions to this rule and care is necessary not to make too broad deductions from tests on a small scale, particularly if of short duration.

EXPERIMENTAL METHODS IN EUROPE

In Europe the water purification problems do not cover nearly so wide or difficult a range of natural conditions as those met in America. Filtration has in recent years not received as much attention experimentally as has been the case with sewage works. In earlier years, however, experimental methods had much to do with the development of water filters abroad. It is not to be forgotten, furthermore, that in Germany much good work during the past dozen years has been done in developing methods for removing iron from ground waters.

England.—In England, which is the home of modern sanitary engineering, sewage purification works have received more attention than in any other country. The density of population in England and the relatively small size of its rivers have, of course, forced this condition at an earlier date than is generally true of other countries. While for some years the English have not contributed much on the subject of water filtration, their

experience in the field of sewage purification far exceeds that of any other country. Experimental methods in one form or another have played an important part for half a century, beginning with efforts to utilize the manurial value of sewage. This is largely owing to the differences in various local conditions, especially topography, geology, and the composition of the sewage as influenced by trade wastes. Not only have the English conducted test filters and other processes of purification on a small scale, but they have also gathered many data of great value by the operation of their works in practice along lines which enable current experiences to be utilized in developing future works.

These data have been so universally obtained in conjunction with the operation of existing works in practice that it is very difficult to ascertain even roughly what their cost has been. The staff regularly engaged in operating the main works has secured the technical data, so that the expense has been confined to building the test devices, relatively small in size, and to a little extra labor for operation. The large mass of valuable testimony published in numerous municipal reports and by the Royal Commission on Sewage Disposal shows what a fund of knowledge has been accumulated at London, Salford, Sutton, Exeter, Burnley, Accrington, Huddersfield, Leicester, Birmingham, Bradford, Hampton, Devizes, Hanley, and other cities, and which for most places has been obtained with almost no special fund devoted to testing purposes, comparatively speaking.

At Leeds unusually thorough sewage tests received appropriations of about $150,000. Manchester has also expended quite large sums for experimental purposes, although, for the reasons above stated, the expenditures were by no means commensurate with the information obtained. The Royal Commission on Sewage Disposal in England is understood to have had an appropriation of about $55,000 for the expenses of its own staff and the traveling expenses of the numerous witnesses who appeared before it. There are also special river boards and county councils, with excellent technical staffs, which gather many valuable data.

France.—In France sewage purification has been the subject of experimental study, beginning with the labors of Mille in 1868 at Gennevilliers. These tests resulted in the establishment of the present sewage farms of Paris. Within the past few years

the biological methods of purification have received attention both from the city of Paris and from the Department of Agriculture. The latter has a general supervising control over water and sewage matters outside of Paris, and had in 1906 an appropriation of about $60,000 for such investigations. Thus far these studies have been made mostly by Prof. Calmette at Lille, as set forth in his interesting progress reports.

Belgium.—In Belgium the government has given particular attention experimentally to the treatment of trade wastes at a special station devoted to that purpose at Verviers.

Holland.—The government of Holland established, in 1904, a sewage testing station at Tilburg, the cost of which was approximately $15,000.

Germany.—In Germany numerous experiments have been made upon the sedimentation of sewage for purposes of clarification, and the so-called biological methods have been studied for some years, beginning in 1895, when a testing station was established by Prof. Dunbar at Hamburg. In 1901 the Prussian government established a permanent organization for testing water and sewage purification methods. This excellent "institute" has gathered together and published the more important data as to experiences in other countries, has conducted several important sewage testing stations in the suburbs of Berlin, and has collated many useful data as to the sanitary works of the cities of Prussia and neighboring territory. This department had an annual appropriation of about $30,000 for testing, inspecting, analytical, and clerical purposes. The sum devoted to testing purposes varies, but is materially supplemented by the arrangement of conducting investigations for various local authorities, the expense for which is borne in part by the community benefited. The department also established the custom of officially examining proprietary devices, largely at the expense of the owners in cases where the devices seem to possess sufficient merit. In this way a mechanical filter of the Jewell type was tested at the Müggelsee plant of the Berlin waterworks.

The relative amounts of suspended matters deposited from sewage at different velocities have been studied carefully under varying local conditions at Frankfort, Cassel, Hanover, Cologne, Essen and elsewhere, as shown by the data published in municipal reports and the technical press. In these cities, as in England, it is difficult to ascertain the cost of the tests, because so much

of the work was done by the regular staff of the technical authorities of the cities. The scope of the tests has probably been greatest at Frankfort, including means for most easily removing sludge, its partial drying by centrifugalization, and its ultimate disposal by incineration after mixing with the city refuse. About $60,000 has been spent at Frankfort on these and other sewage tests, including filtration, within the past dozen years or more.

Prof. Dunbar's activities in the field of sewage purification have by no means been confined to Hamburg. His publications show that he has advised the authorities at Mühlhausen, Stuttgart, Beuthen, Unna, Leipzig, and other places. In nearly every instance he has taken advantage of experimental data to ascertain local conditions. Leipzig and Chemnitz in Saxony were conducting sewage tests in 1906, the appropriations for which were about $17,000 in each case, with the engineering and analytical data secured by men regularly employed by the city.

In the Emscher sanitary district in western Germany experimental methods were availed of to a substantial degree in the preparation of a working program which since 1906 has attracted much favorable comment from various parts of the world. In particular has success attended the practical use of septicization in two-story tanks of the Imhoff type.

This brief record of experimental methods as applied to sewage purification can hardly be brought to a close without reference to trade wastes. This feature in aggravated cases complicates the design of sewage works and adds materially to the costs of operation. Various industries require special consideration, as shown by the efforts of the river boards to minimize the effect of trade wastes in the streams of Lancashire and Yorkshire, England. The removal of fats has perhaps received the most attention along this line—especially in Berlin, Cassel, and Chemnitz in Germany, Verviers in Belgium, Roubaix and Grimonpont in France, and Bradford, Manchester, and Oldham in England. Numerous mill-owners also recover grease from their waste water. The extent of some of these investigations is indicated by the fact that at Cassel a private company is said to have spent considerably more than $100,000 in unsuccessfully endeavoring to fulfil a contract for extracting fats from the city sewage. The only large place where the

entire city sewage is regularly treated for grease extraction is at Bradford, England.

RÉSUMÉ

Experimental data from a combined engineering, chemical and biological viewpoint have been a powerful factor in promoting efficiency and economy in sewage disposal projects. Particularly was this true some years ago, when it was out of question to secure data from works in practice. Their utility is less now than formerly, and designing engineers now look more to results of operation on a large scale. But the establishment by tests on a small scale of underlying principles of sewage disposal, even if meager sometimes as a guide to completely satisfactory designs, has been of notable aid in the advancement of this field of sanitary science.

CHAPTER VIII

DILUTION IN INLAND STREAMS

The disposal of sewage by dilution is a proper method when by dispersion in water the impurities are consumed by bacteria and larger forms of plant and animal life or otherwise disposed of so that no nuisance results.

FREEDOM FROM NUISANCE

Unquestionably there are cases where sewage disposal by dilution is followed by self-purification of the diluting water so that all reasonable sanitary requirements are met. On the other hand, there are a great many instances where this method is not suitable at all times unless the sewage is given some form of treatment.

It is usually a long step in point of expense from dilution to efficient filtration. Between the two are several intermediate processes or methods of sewage treatment.

No attempt will be made to lay down hard and fast rules of procedure, as that is out of the question at the present time, when viewpoints on the subject are so variable. It is desired, however, to explain the leading evidence on the subject with considerable care.

In Chapter VI it has been made plain that different problems require different treatments to secure freedom from nuisance. With the dilution method particular attention should be given to the following points:

1. The diluting water should show no signs of floating matters offensive to the eye, or which may become stranded upon margins of the stream.

2. Coarse solid matters, if need be, should be removed, so that in the diluting water there will not be formed, near sewer outlets or at shallow places, or in front of dams, objectionable banks of sludge or sewage solids. Where the stream is deep and with a good current at all times, as in the lower Mississippi, this is not much of a factor. On the other hand, this is a

conspicuous cause of offense in many streams having a small dry-weather flow. The same may be said of some ferry slips.

3. Velocity of flow of the diluting water is of much practical significance. If it is always high enough to prevent substantial deposits of sewage mud or sludge it is of great aid to the efficient working of the dilution method. If scouring velocities ordinarily prevail at sufficiently frequent intervals to prevent seriously offensive results from decomposition of sludge, much benefit is also secured from stream velocity. But if depositing velocities normally prevail the decomposition of sewage mud needs much careful attention, depending upon the depth and frequency of change of the overlying water. In some cases such velocities permit of thoroughly satisfactory results only in connection with the removal of settling solids either from the sewage or from the bed or banks of the body of water into which the sewage is discharged. Dams, which reduce the velocity of flow for long periods at a time, aid in the clarification of streams receiving raw sewage; but the sewage sludge frequently decomposes so as to add materially to complications from offensive odors and the deoxygenation of the overlying water.

4. The dispersion of the sewage in diluting water should be such that all of the sewage may undergo bacterial decomposition on an aerobic basis. In other words, maintain the "oxygen balance," as explained in Chapter I, on a safe margin for guarding against anaerobic decomposition with its foul odors, as explained in Chapters II and III. This deals specifically with the degree of dilution which will be touched upon later in this chapter.

5. In providing for a safe margin in the dissolved oxygen content of the diluting water care should be taken to provide a residual of oxygen sufficient for reasonable requirements of major fish life.

6. Trade wastes are liable to prove injurious to bacterial and other forms of life and upset estimates which otherwise are based on sound experience elsewhere. In many streams they do far more mischief than does domestic sewage. In all manufacturing valleys they require special study.

7. Time is an important element in studying the deoxygenation of a stream by the sewage which enters it. In Chapter I the effect of time has been explained in Table 20, page 38. Further illustrations are found in the tables on pages 67 and 69. In practice this factor is of more importance than hitherto con-

sidered. It should be studied with respect to the duration of flow from the point of initial pollution to lower points where there is either added pollution by sewage or additional dilution from incoming streams.

8. Much care should be given to the influence which disease germs of sewage origin may have on neighboring water supplies or shellfish layings. This involves questions of sanitary and business policy as well as of local laws.

PROCESSES INVOLVED

Disposal by dilution is just as real a method as is filtration. Technically it is perhaps more complicated in its adaptation to a series of problems. Ordinarily it involves works which are simpler and cheaper both to build and operate.

It should not be inferred that because a method has been crudely and improperly applied for economical or other reasons it is not worthy of the most careful study.

The dilution method involves the consideration of the following processes:

a. Flotation.

b. Sedimentation.

c. Food supply with respect to grosser microorganisms serving in turn as food supply for fish.

d. Aerobic and anaerobic decomposition of sewage by means of the bacteria.

e. The maintenance of a proper "oxygen balance" throughout the entire body of diluting water.

f. The maintenance of a residual percentage of oxygen in the diluting water which reasonably meets the requirements of major fish life.

g. Bacterial removal with respect to longevity of disease germs, and their deposition in the stream, during the period of transit from the point of entrance of sewage to the location of neighboring water supply intakes or shellfish layings.

HISTORICAL DEVELOPMENT

Originally it was the almost universal custom to dispose of water-carried household wastes by conveying them to the nearest watercourse. There are a few exceptions where efforts were made to utilize the manurial value of the sewage, but they were so few that these instances may be ignored.

As the population increased at numerous places and the volume of sewage became greater and greater, a large number of important streams throughout the world became grossly polluted. This was true at London, Paris, Berlin, Chicago, and numerous smaller places long before modern bacteriology was recognized as a science. It resulted from the overtaxing of the diluting power of the water and the consequent anaerobic decomposition products with their attending bad odors.

Even to-day it is safe to say that the disposal of sewage by dilution is the prevailing method. It is almost universal for conditions where no gross nuisances result, or where in case of new works no nuisances are likely to arise, judged by experiences elsewhere.

Indeed, the existence of nuisances has not been sufficient to prompt the correction of flagrant instances of the overtaxing of the diluting power of streams which receive sewage. To a greater extent than most people realize active or prospective litigation has prompted communities to adopt sewage treatment works.

In early years the expense of such works was considered for many localities an unbearable burden. More recently, since the development of the so-called biological processes, cities have progressed with care in the hopes of securing works involving a minimum of expenditure. This is true even in those states where public health laws direct the elimination of objectionable sewage pollution of streams.

The present status of sewage disposal by dilution is unsettled. It is generally recognized by those having most to do with this line of work that it has an indisputable field of usefulness, but that much more care must be applied in its utilization than has been the case hitherto. Obviously, there are cases where treatment works are required, but it by no means follows that this should be the practice universally. The questions then arise, What are the conditions for the proper use of this method and where does the limit come in its applicability?

EXTENT OF USE

In 1904 the author found that of the total urban population in the United States, as indicated by cities and towns of over 3000 population, there were over 20 million people discharging raw sewage into inland streams or lakes. At that time there

were about 1,100,000 people connected with systems where sewage purification works were employed. Since that time there have been quite a number of inland cities to adopt sewage purification, the larger being Columbus, Ohio, and Reading, Pa., while a number of others, such as Atlanta, Ga., Waterbury, Conn., Gloversville, N. Y., and numerous smaller ones, have works under construction. Taking into account the increase in population, it is doubtful if the percentage of population which now has its sewage purified is materially different from that indicated by the above figures.

Compared with the corresponding data from European countries it is seen that in America sewage disposal in works of artificial construction to secure substantial purification is still in its infancy. Scarcely any of the municipal works have been in service more than 20 years, and the majority of the plants have been built during the past ten years.

This situation is not so extraordinary as would appear at first glance, owing to the large waterways along which so many American cities have been built. American rivers in comparison with European streams are relatively great, although of course there are numerous small streams in America.

A factor of perhaps some importance has been the absence of any central authority to promote a definite program for solving sewage disposal problems in this country. Except through the Federal courts, the United States Government has generally left these matters alone in the absence of any authorization from Congress. Thus the different states and municipalities have dealt with the problems as they saw fit.

Washington Plant.—At Washington, D. C., the Federal authorities have themselves adopted the dilution method under careful and apparently adequate conditions of dispersion of the sewage in the Potomac river after removal of some of the coarser suspended matters. This project was developed by a special commission of engineers composed of Messrs. Hering, Stearns and Gray, appointed by the late President Harrison in 1889.

In their report the engineers stated as their conclusion that there is enough water flowing in the Potomac river at all times to dispose of the sewage of at least 800,000 inhabitants without causing offense. This result is predicated on the sewage being mingled uniformly with the whole volume of river water and dispersed in a place where the suspended particles in the sewage

cannot deposit or cause offense. A description of these works will be found in the *Engineering Record* of Aug. 22 and 29, 1908. Fig. 3 shows the sewage pumping station at Washington, and illustrates the character of the construction work. It was furnished through the courtesy of Mr. Asa E. Phillips, Superintendent of Sewers of the District of Columbia.

Col. W. M. Black, Engineer Corps, U. S. A., in his report of October, 1909, as to the New York harbor conditions, describes the results of an inspection trip to Washington to note the

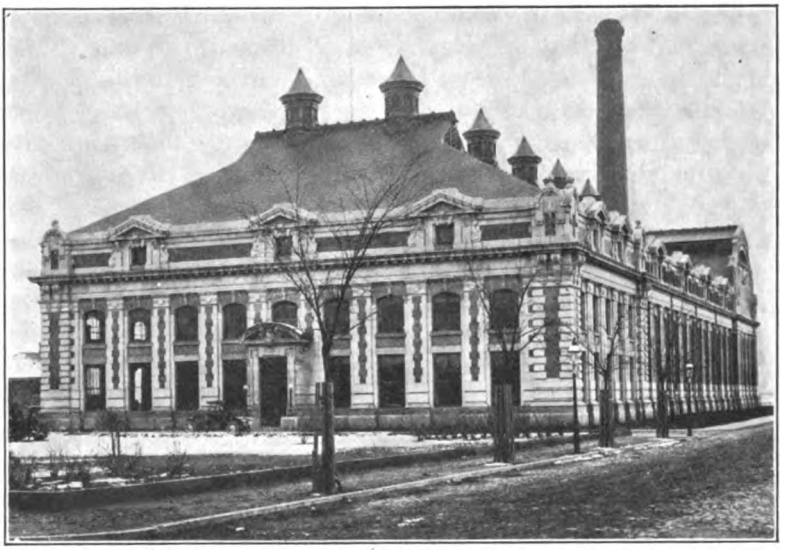


FIG. 3.—Sewage pumping station Washington, D. C.

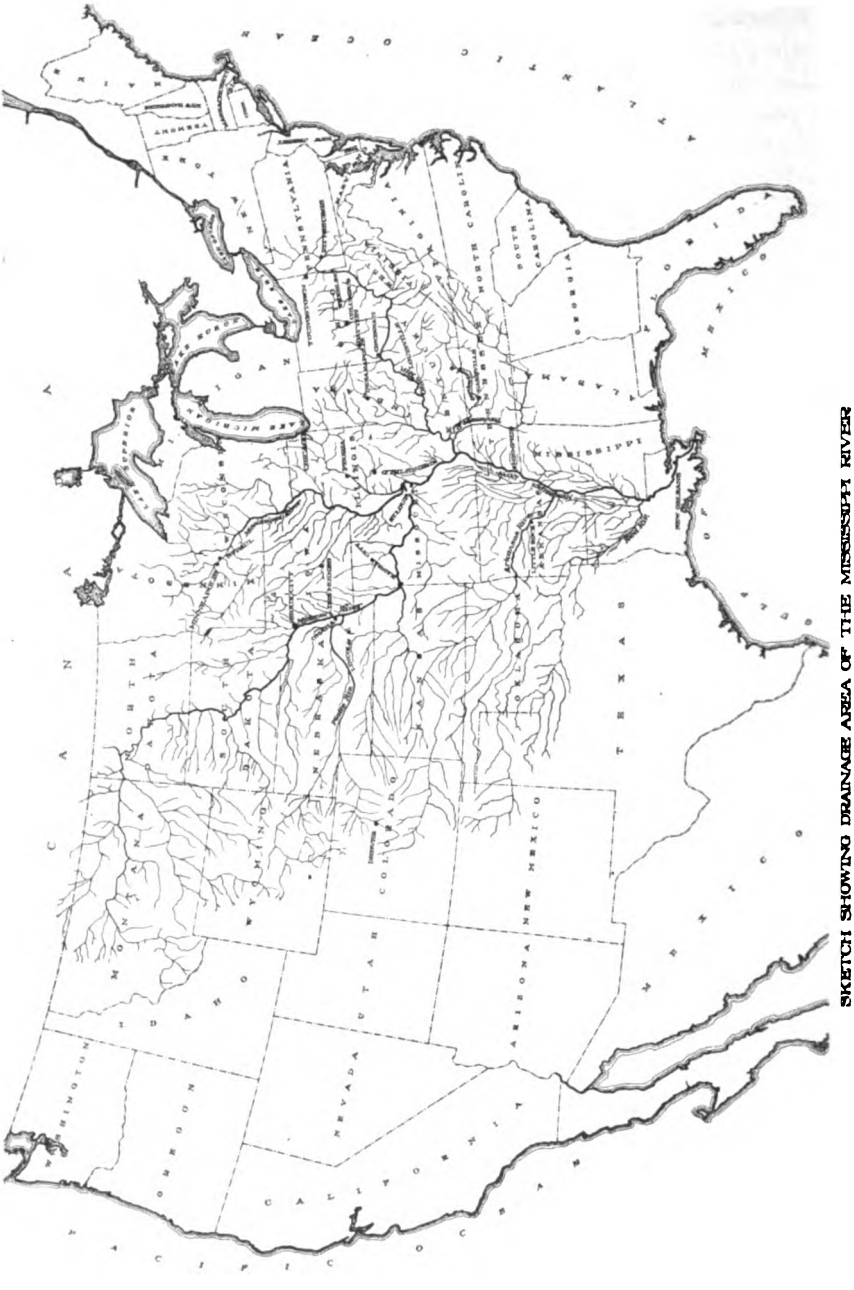
sewer outlets in the Potomac river. The discharge is through two outlets in fresh water about 28 feet deep. It is stated that it was difficult to find the exact point of discharge from surface indications. The color of the river water was nearly that of the sewage, so that the river water was very slightly discolored. Only a very slight odor was perceptible at the outlets, and the area of discoloration was about 30 feet wide by 250 feet long. Mr. Phillips states that the dissolved oxygen in the Potomac river near the dilution area seldom becomes less than 60 per cent. Usually it is much higher than this and only twice has it been 50 per cent. or less.

Résumé.—Disposal by dilution is by far the predominating method now in use in America. It has been superseded only in cases where it was conspicuously inadequate. The details of the disposal works by dilution are in general far below the requirements of successful practice in utilizing this method. Sanitary engineers feel that in many cases the dilution method may be availed of, as in the instance at Washington, D. C., in a thoroughly satisfactory manner. At most places, however, the sewer outlets by no means allow the sewage, in proper condition, to be suitably dispersed in the flowing stream. Filtration plants are no doubt required in some instances, but simpler and cheaper devices will allow some problems to be solved satisfactorily. Ultimately the "liquid portion" of all sewage must reach the watercourses, unless by chance it should be used in steam boilers or other ways to divert it from the normal channels.

SELF-PURIFICATION OF STREAMS

At New Orleans the muddy Mississippi river water showed during 1901–02 almost no trace of sewage pollution either as to organic matter or disease germs, although on the watershed there were about nine million people discharging sewage into this stream and its tributaries. Careful tests were made at frequent intervals for many months by Mr. R. S. Weston, as stated in his report of Jan. 1, 1903, upon water purification investigations, pages 47 and 188. He made about 100 tests for B. coli with volumes of water varying from 1 to 300 cubic centimeters but its presence was demonstrated only three times. This result shows more decisively than any other information available that self-purification is a real phenomenon of large rivers.

It is true that the conditions of the lower Mississippi are unusual in that it is a very large river and that for about 600 miles above New Orleans there was in 1902 comparatively little drainage into the river. Since that time Vicksburg and Natchez, Miss., have extended their sewer systems, but the result in quality of river water at New Orleans is understood to be substantially unchanged. The mean and minimum stream flows of the lower Mississippi are approximately 700,000 and 200,000 cubic feet per second, respectively. A sketch of the drainage area of the Mississippi river, including the Chicago Sanitary District, is shown on Fig. 4.



SKETCH SHOWING DRAINAGE AREA OF THE MISSISSIPPI RIVER

FIG. 4.

English Rivers.—In England, where the rivers are small and the population dense, it has been the belief for years that rivers are not long enough to purify themselves from the effects of sewage pollution. While that is true as a general rule, there are exceptions within certain limits to be noted even in England. The river Severn near Shrewsbury was shown to purify itself to a substantial extent, especially as indicated by chemical tests, as stated in the Second Report of the Royal Commission on Sewage Disposal, 1902, pages 106–09 and 132.

Objectionable Bacteria.—Among the objectionable bacteria of sewage origin are conspicuously the germs of typhoid fever and Asiatic cholera. There are others related to intestinal diseases, as indicated in Chapter IV. So far as known none of the sewage bacteria multiply in surface waters. It is a question of how long they will survive in diminishing numbers, as explained in Chapter IV. Where the distances and time intervals are great between the point of pollution and point of examination the elimination of objectionable bacteria may be substantially complete. This was found to be the case with the lower Mississippi river water at New Orleans, as above stated. Here the pollution was removed for more than 600 miles owing to the fact that the drainage is away from and not into the river in the so-called delta country. From Chicago to the Mississippi river the distance is about 357 miles, and during high and medium stages of water the Chicago sewage would reach the St. Louis intake in from about 8 to 15 days. Comparatively speaking, there were substantially no signs of bacteria from the Chicago sewage reaching the St. Louis water supply.

In the majority of cases the period of flow from the point of pollution to the neighboring water supply is much shorter than in the instances here stated. It is necessary to recognize, therefore, that for ordinary cases self-purification of streams does not provide an adequate, reliable means for the removal of sewage bacteria of an objectionable character if the water of the diluting streams is to be consumed in a raw state by neighboring communities. This brings up the question of policy as related to the filtration of surface water supplies, and also of the sterilization of the sewage, or of the water supply, or both. This will be discussed under a separate heading.

Here it may be said that a factor of bacterial importance is the question of storm overflows from combined sewers.

Floating and Settling Solids.—Scientifically speaking, these matters should be removed from sewage before the latter is allowed to enter a body of water. This is rarely the case and shows a marked discrepancy between theory and practice as the art of sewage disposal now stands. Floating matters are offensive to the eye, and when they become stranded along the shore frequently give just cause for complaint. Theoretically sewage should be freed from those coarser solids which would subside in a stream under the conditions of velocity to be encountered by the diluted sewage. If the sewage is first screened and subjected to sedimentation with as low a velocity of flow as experienced in the river, then this feature may be said to be kept well in hand. This is in fact the procedure aimed at in many cases in Europe and a number of recent projects in this country.

Sewage mud, so called, is composed in a considerable measure of organic matters which will undergo bacterial decomposition. If the stream is very deep offensive gases arising from the sewage mud may be rendered inoffensive through the combinations into which they enter as they pass upward through the overlying water. In shallow streams, however, particularly in millponds, sewage mud is frequently bothersome. But the method of dilution should not be discarded entirely because in practice the sewage is not now properly clarified in most instances. Here it is to be borne in mind that anaerobic decomposition of sewage mud is liable to occur notwithstanding that there may be enormous volumes of well-oxygenated water at all times overlying the deposits upon the bottom and sides of the stream. Perhaps this statement would be more precise if limited for the sides of the streams to a zone beneath which aeration does not become a factor on account of wind action. This reservation, however, is not of much practical significance in ordinary streams with varying water levels.

In résumé it may be said that self-purification is not capable of dealing effectively with those matters which either float or subside, although in some rivers the volumes and velocities of flow are such that no serious difficulty is encountered.

Aquatic Life.—In America due attention has not been paid to the aid in purification which streams receive from various forms of plant and animal life other than the bacteria. Different forms undoubtedly consume much more of the sewage matters both in suspension and in solution than is generally realized. In

England and Germany this question has been given more serious consideration. At the close of this chapter is an abstract of a lecture by the late Prof. Marsson of the Royal Prussian Institute and which has been excellently translated by Mr. Emil Kuichling. The question needs further study in this country, both as regards the self-purification of streams and the part which this aquatic life plays as a food supply for fish. In Chapter IX this subject is touched upon through the excellent investigations of Messrs. Birge and Juday in connection with the Wisconsin lakes. Muddy rivers would no doubt show a much different set of results than those obtained either in clear rivers or ordinary lakes. The reason of this is the exclusion of sunlight which plays a prominent rôle in the development of some types of aquatic life.

These forms of life also require consideration as to the dissolved oxygen which they add to or take from the diluting water.

Organic Matters.—Soluble and non-settling organic matters in sewage are capable of oxidation either in a stream or in a filter. In either case the work is accomplished directly by bacteria or indirectly by enzymes in the presence of oxygen. This brings up again the question of "oxygen balance," which has been touched upon at length in Chapters Iand II. We will say no more here other than to point out that not only must there be sufficient oxygen to maintain bacterial decomposition on an aerobic basis, but there must also be a margin sufficient to protect major fish life. This oxidation is the real province of sewage dilution, and under proper conditions it may be availed of, although it may involve a prior sedimentation and sterilization of the sewage. It brings effectively to the front the important questions of adequate dispersion of sewage in a body of diluting water and of the degree of dilution therein.

THE QUESTION OF POLICY AS TO BACTERIAL REMOVAL

The foregoing discussion is intended to make plain the essential principles of the dilution method, as follows:

1. **Floating and Settling Solids.**—Dilution in water does not ordinarily deal satisfactorily with these matters. There are some exceptions to the rule. Generally speaking, the solids should be removed before dispersing the sewage in water.

2. **Organic Matters.**—The oxidation of soluble and non-settling organic substances in sewage through the aid of the bacteria,

aerobic decomposition, is the special field of usefulness of the dilution method. This should not be overlooked on account of shortcomings in the method as to floating or settling solids, or to the removal of bacteria.

3. **Bacterial Removal.**—The bacterial self-purification of streams cannot be relied upon for a sufficient elimination of the objectionable bacteria of sewage, if the water is used for drinking purposes in a raw condition. Exceptions to this statement are scarcely to be found, even in the above-quoted instance at New Orleans, La. Corresponding statements also hold true of shellfish layings within certain limits, about which our knowledge is meager.

4. **Water Purification Needed.**—In Europe there are several countries, particularly Germany and England, where it is practically obligatory to filter carefully all water supplies from surface sources. Excepting a few supplies where the water from sparsely inhabited areas is stored for long periods, this is the course which with much benefit has been pursued in this country during recent years. Soil washings from rural districts and the overflows of storm-water sewers in cities make it out of the question, in the judgment of the author, to rely ordinarily on obtaining a safe water supply from raw river water. Accordingly it is believed to be unnecessary to remove the objectionable bacteria of sewage in some cases. In others it is important to do so to a degree to relieve the load on the water purification plant.

5. **Changing Viewpoint.**—Many sanitarians and medical men are clamoring stoutly for the elimination of all sewage matters from American streams. Literally this is impossible. No longer can there be streams of pristine purity in populous districts. This is one of the penalties of civilization.

On the other hand, it may be freely stated that many streams are now polluted to a disgraceful degree. Corrections are most urgently needed. This subject is being discussed as to standards of purity for rivers by a committee of the National Association for the Prevention of the Pollution of Rivers and Waterways. An account of the last meeting of this Association is given in *Engineering News* of Dec. 21, 1911.

6. **Needed Sense of Proportions.**—While it is possible to purify sewage to almost any degree, the expense of doing so as thoroughly as called for by the sentimentalists is prohibitive in some instances. Much more good is accomplished by

treating the public water supplies so as to make them above reproach. The relative solution of water and sewage problems should be taken up for each valley in a scientific practicable way. In doing so it is necessary to bear in mind that the public health demands consideration of the solution of other problems which cost much money. Theoretically the treatment of sewage should not be made so complete that the sanitary benefit derived therefrom is incommensurate with the cost involved. At present there is great need of a keen sense of proper proportions in solving these and other sanitary questions. This subject is ably dealt with in a report by Messrs. Hazen & Whipple, endorsed by Messrs. Stearns and Eddy, on sewerage and sewage disposal coditions at Pittsburgh, Pa., as reviewed in *Engineering News* of Feb. 24, 1912.

7. **Sterilization Available.**—Fortunately there is now available by the hypochlorite method a reliable means of sterilizing or disinfecting sewage or water at a small cost. The full significance of this is not yet fully appreciated. It has much bearing on the question of sewage disposal in general and on the dilution method in particular, as related to some conditions. The method is described in a subsequent chapter.

Policy.—We are passing through a transitional stage of developments in the field of sewage disposal. Viewpoints vary widely and needlessly. There is no reason now to believe that the views of the extremists on either hand will ultimately prevail.

Sewage disposal in America must be materially improved, but along economical lines of intrinsic and adequate sanitary merit.

No longer is it necessary to try to produce "spring" water by land treatment or sand filtration. Sterilization methods, carefully applied, serve equally the hygienic requirements.

When coupled with sterilization the dilution method is entitled to full consideration for its practicability and economy as a means of oxidizing soluble and non-settling organic matters.

CORRECTIVE MEASURES

The needed improvements at present in the use of the dilution method may be readily inferred from the foregoing discussion. They will be more apparent upon reading subsequent pages on which are recorded some of the actual conditions to be reckoned with in practice. They include the following:

1. Eliminate floating matters and those settling matters which would make objectionable sludge deposits.

2. Sterilize the clarified sewage where and when necessary.

3. Disperse the treated sewage in water so that it may be properly oxidized.

We shall now discuss some of the features of the latter class of needed improvements.

DEGREE OF DILUTION—THE OXYGEN BALANCE

The amount of dilution required to maintain a suitable degree of stability in the diluting water depends much upon the character of the sewage, particularly as to the effect of trade wastes and street washings. The quality of the diluting water is also an important factor, as to the content of dissolved oxygen. Another item is the amount of organic matter in sewage sludge or deposits from soil washings, over which the water flows and which may deoxygenate the water. Time and temperature are also important.

Where the degree of dilution is less than about 3 cubic feet per second for each thousand population, connected with the sewers there is strong likelihood of offensive anaerobic decomposition ensuing.

In some instances, where trade wastes are a factor, it may be that the degree of dilution should be more than double this figure.

Studies along the lines instituted by Prof. Phelps as to the stability of sewages and the rate at which they deoxygenate water under different conditions should do much toward making more precise our views upon this matter. It is a question upon which much evidence has been obtained along more or less precise methods of observation. Quite a complete summary of this evidence will be given in this chapter.

Chicago Data of 1911.—On Oct. 12, 1911, Mr. G. M. Wisner, Chief Engineer of the Chicago Sanitary District, submitted a valuable report on the results obtained with a dilution approximating the legal limit in the drainage canal, 3.3 cubic feet per second per thousand population. The figure is too low for local conditions. It is about 35 miles from Lake Michigan to the foot of this canal at Lockport, as shown in Fig. 5. During the summer dissolved oxygen was frequently exhausted in the water of the canal during its flow for 10 to 15 miles above Lockport. The water was putrescible, with a stability number of less than 10, as will be noted from Table 48, page 259.

Under local conditions industrial wastes make large demands upon the dissolved oxygen as do the sludge deposits in the water courses in the city limits of Chicago and in the canal itself. In consequence, fish life is practically eliminated from the canal.

Precise Rule Impracticable.—It is the judgment of the author that each problem should be studied on its own merits with

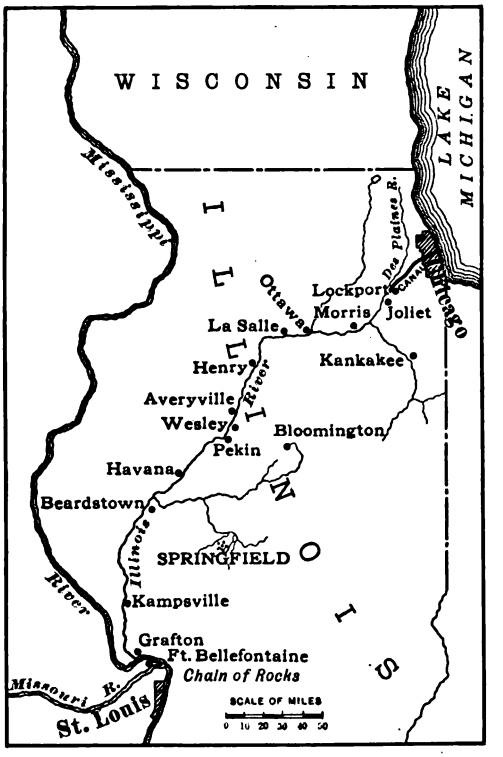


FIG. 5.—Drainage area of Illinois river.

respect to its local individuality. Furthermore, the range above given in permissible dilution for purposes of oxidation is as satisfactory as can be now stated. More precise data are needed. Particularly is this true as to the provisions to be made for fish life in streams. Where sluggish rivers are covered with ice for long stretches for several weeks at a time, the dilution may have to be materially increased. Trade wastes and sludge, if dealt with, also require an increase in dilution above the lower limits.

Influence of Clarification.—The fairly coarse matters which

are removed by screens or sedimentation basins are not the unstable portions of sewage, comparatively speaking, which are decomposed readily by bacteria and which require oxygen to keep the process of deoxygenation within proper limits. The subject will be discussed later. Briefly it may be said that the stability of sewage is practically uninfluenced by screening. By sedimentation there is a removal of about 25 per cent. of the unstable organic content of ordinary city sewages. Where the sewage is very fresh the removal would probably be more than this figure. In time the sludge deposits, however, deoxygenate the overlying water.

Appearance.—A dilution of 4 cubic feet per second per thousand population is equivalent to saying that the sewage of one person per day would on an average be diluted to 2585 gallons. This corresponds with a dilution of about 25 times for sewage of ordinary strength, say 100 gallons per person daily. After sedimentation it is found that ordinary American sewages contain a range of from about 50 to 100 parts per million of non-settling solids. When uniformly diluted with 25 volumes of river water there would be no objectionable turbidity due to the sewage. It could not be detected by the eye. Indeed it could scarcely be detected by laboratory tests in the case of turbid or colored streams.

Immediately around some large sewer outlets the sewage flow might not receive its full dilution. Even if this were not remedied by suitable multiple outlets, a small field of slightly noticeable turbidity should scarcely be rated as objectionable. Its area would probably be much smaller than that of a filtration plant.

At the foot of the Chicago drainage canal during the warm season of 1911 Mr. Wisner's report indicates that the total suspended matter in the canal water ranged from 12 to 74 and averaged 32 parts per million. Rarely does it increase materially the turbidity of the Illinois river.

DISPERSION—MIXING

Dispersion should be far more carefully considered than generally found in practice at this time. Where a stream is adequate in its volume of flow for dispersion of sewage, the results are frequently unsatisfactory owing to the improper mixing of the sewage with the water.

The tendency is to convey the sewage only to the edge of the stream, with the result that marginal pollution exists, while little or no benefit is derived in midstream of the power of dilution. This has resulted in several recent designs in the providing of outlets at a number of points along the cross section of the stream. Full advantage has by no means been taken of this method of avoiding marginal pollution by what is generally spoken of as multiple outlets.

In some cases bends or curves in a stream bed promote mixing. Currents, eddies and similar features should be carefully studied.

RESIDUAL OXYGEN

The residual oxygen should not only suffice to maintain decomposition of the sewage on an aerobic or oxidizing basis, but also to provide reasonably for fish life. Evidence upon this point is not well crystallized. It differs undoubtedly for different species of fish.

Some advocate 70 per cent. as a proper quantity of oxygen, expressed with reference to saturation, to remain in the diluting water at all times. This is spoken of by Messrs. Black and Phelps in connection with New York harbor problems in their report to the Board of Estimate and Apportionment in 1911. In the opinion of the author this limit is needlessly high.

On the other hand, those who have followed these matters most carefully in Europe and in this country feel that 30 per cent. is a reasonable margin as a minimum; and that for some species of fish a residual of 20 per cent. is not prejudicial for a limited area around the point of dispersion.

No attempt will be made to summarize the evidence which is mostly of European origin, as it is a subject which needs a comprehensive investigation. Reference is made to the fifth Report of the Royal Commission on Sewage Disposal of Great Britain, Appendix VI, page 205. It has been the author's recent practice to place the reasonable limit at 30 per cent., which has been considered more than sufficient for the most important fish life, although there may be some kinds for which this is rather small.

In practice it is likely that fish will avoid the immediate neighborhood of a sewage dispersion field if the oxygen is found deficient. In other words, they move to a more congenial environment. From this standpoint it is doubtful if tests should

be taken too seriously when made in small vessels and where the fish consume the oxygen from the small body of water in which they are confined. On the other hand, it only takes a short time to suffocate fish if the oxygen were exhausted throughout the entire body of water due to some unusual condition.

Chicago Conclusion.—In Mr. Wisner's 1911 report it is concluded that a minimum of at least 2.5 parts per million of dissolved oxygen should be kept in the Illinois river below the Marseilles dam at all times. It is further stated that it would be desirable to have the amount always around 3.5 to 4 parts, but that specific tests are needed on various kinds of fish.

Between the canal and Marseilles the water flows over the Lockport and Joliet dams and through quite long stretches of rapids below Joliet.

The minimum limit above given is equal to about 20 per cent. of saturation of oxygen for winter and 30 per cent. for summer temperatures. The number of parts is a preferable expression to percentage of saturation.

ATMOSPHERIC OXYGEN DISSOLVED IN WATER

As is well known, the amount of atmospheric oxygen which water will absorb varies with the temperature and pressure. The majority of data in this country have been expressed either in parts of oxygen by weight or in percentage of saturation at the temperature of the sample as collected.

Recently results have been expressed as the number of cubic centimeters of the gas per liter of water. This follows the practice of the Royal Commission on Sewage Disposal of Great Britain. It has been adopted by the Metropolitan Sewerage Commission of New York and also in important work in the study of the Wisconsin lakes by the local State Geological Survey.

In round numbers one part per million of dissolved atmospheric oxygen by weight in one million parts of water corresponds with 0.7 cubic centimeter of atmospheric oxygen per liter of water.

Parts per million may be converted into pounds per million gallons by multiplying by 8.34.

In the "Standard Methods of Water Analysis" published by the American Public Health Association in 1905 the amount of atmospheric oxygen required to saturate water at different temperatures is given as stated in Table 41:

TABLE 41.—QUANTITIES OF DISSOLVED OXYGEN IN PARTS PER MILLION BY WEIGHT IN WATER SATURATED WITH AIR AT THE TEMPERATURE GIVEN

Temperature C.	Oxygen	Temperature C.	Oxygen
0	14.70	16	9.94
1	14.28	17	9.75
2	13.88	18	9.56
3	13.50	19	9.37
4	13.14	20	9.19
5	12.80	21	9.01
6	12.47	22	8.84
7	12.16	23	8.67
8	11.86	24	8.51
9	11.58	25	8.35
10	11.31	26	8.19
11	11.05	27	8.03
12	10.80	28	7.88
13	10.57	29	7.74
14	10.35	30	7.60
15	10.14		

It should be kept in mind in comparing these results that they are obtained for the atmospheric oxygen actually dissolved in water, and are therefore the outcome of actual tests, and not computations by formula either for atmospheric oxygen or pure oxygen. Samples of water collected below the surface have usually had their oxygen content expressed at a normal pressure of 760 millimeters.

INITIAL OXYGEN

The stability of diluted sewage naturally depends much upon the initial oxygen content of the diluting water. This is influenced strikingly in practice by the temperature of the water and the extent to which it has been previously deoxygenated by organic matter and organisms living thereon.

In winter, water that is near the freezing temperature contains about 14 parts of oxygen when saturated. During summer the corresponding figure may be about 8 parts.

As pointed out in Mr. Wisner's report, 1000 cubic feet of lake water in summer provides only as much oxygen for self-purification in the canal as do 585 cubic feet in winter. With waters which are more polluted than this lake water, the difference would be greater.

REAERATION

Water absorbs oxygen at its surface when exposed to the air. By diffusion the oxygen moves to lower depths. This is quite a slow process and its effect in practice is not very clearly defined.

Wind action promotes mixing and the carrying of oxygen from the surface to lower depths.

Aeration by flowing over dams or rapids aids materially in maintaining a high oxygen content.

On the other hand, when ice covers completely a sheet of water, the absence of reaeration asserts itself sometimes in a striking way.

The oxygen content of Massachusetts waters was described in the 1902 report of the Massachusetts State Board of Health by the late Dr. T. M. Drown.

In Prof. W. P. Mason's book on "Water Supply," page 192, the oxygen content of waters is discussed. Mention is made of the studies by the late Prof. Albert R. Leeds of the Schuylkill river in Philadelphia during the winter of 1882–83 when ice cut off the oxygen supply. Foul-smelling gases of decomposition made much trouble for the water consumers. Their character is mentioned in the *Journal of the Franklin Institute*, Vol. LXXXVI, page 26.

SEASONAL EFFECTS

At the warmer temperatures of the spring and summer biological activities are greater than during the winter. More oxygen is therefore required during the summer than during the winter in order to maintain the oxidation of organic matter on a satisfactory basis, when the time interval is the same.

In this connection it is of interest to note the dissolved oxygen content of the Merrimac river at Lawrence, Mass., where it serves as a source of the city water supply after filtration. The data in Table 42 are copied from page 39 of the book of Messrs. Kinnicutt, Winslow and Pratt. They are given in that book as illustrative of conditions where malodorous results occur at times

of low summer flow. It is correctly stated by these authors that while any dissolved oxygen remains there should not be "putrefaction." But they add that practically any value below 50 per cent. of saturation is likely to be accompanied at times by malodorous conditions. This last statement should not be taken too seriously as applicable to problems where sludge deposits and reasonably complete mixture of the sewage with the water are provided for. It accentuates, however, a result that is found at some places where improper mixing causes shore pollution and where stranded sewage solids produce offensive deposits.

TABLE 42.— SEASONAL CONDITIONS IN MERRIMAC RIVER AT LAWRENCE, MASS.

Month	1899			1900		
	Flow per 1000 persons discharging sewage (second-feet)	Temperature, degrees Fahrenheit	Dissolved oxygen (per cent. of saturation)	Flow per 1000 persons discharging sewage (second-feet)	Temperature, degrees Fahrenheit	Dissolved oxygen (per cent. of saturation)
January	42.6	34	96.3	18.2	33	81.6
February	26.4	34	88.1	89.1	34	87.8
March	64.5	34	95.6	87.7	35	.....
April	143.2	.....	99.3	100.0	41	99.1
May	51.6	58	84.4	54.1	54	.....
June	16.1	73	71.1	21.4	73	62.1
July	13.4	76	66.6	9.8	77	59.4
August	11.3	74	58.3	10.1	75	43.6
September	10.8	67	57.2	8.2	71	32.5
October	9.7	58	53.7	13.6	62	47.6
November	15.1	40	78.1	31.6	46	91.2
December	15.1	36	84.3	36.6	38	98.0
Average	34.5	53	77.8	39.9	53	70.3

The summer is the time when the initial oxygen content is least, although the opportunity for reaeration is greater than for ice-covered streams. It is also the time when the natural flow of streams is smallest.

The Chicago drainage canal is in better condition in winter than in summer. Study of the old Chicago reports indicates that the degree of dilution was adjusted more to winter than summer conditions.

AQUATIC GROWTHS

Animal and vegetable life other than the bacteria are to be considered carefully with respect to the oxygen balance. Some chlorophyl-bearing organisms produce oxygen, but normally they consume it in their respiratory processes. The question is discussed later in this chapter, and also in the next chapter as related to Wisconsin lakes.

Some of these growths are direct consumers of organic matters and have an important relation to fish life.

In shallow sluggish streams the physical detention of suspended sewage matter by aquatic growths is a factor.

TIME FACTOR

As is true of the incubation or putrescibility test, and illustrated in Table 20, the factor of time is of much importance in the deoxygenation and self-purification of rivers by bacterial action.

If the Chicago drainage canal were one-tenth of its present length and then discharged into the Mississippi river, it would produce a better result than now obtains, as to deoxygenation in the canal, but the oxidation of organic matter would be less complete.

On the other hand, if it should flow for ten times its present length at the same velocity, and uninfluenced either by the diluting water or the pollution of the Illinois valley, then the anaerobic decomposition would probably make odors far more pronounced than now exist.

The lower Mississippi river gets the benefit of this long time interval and shows the result in the completeness of the self-purification. In small streams that are not overloaded, the time factor is too short to show much improvement in the water.

In résumé it is to be said that when the degree of dilution is adequate the self-purification of the stream on an aerobic basis will become more complete as the time interval increases. But if the dilution is inadequate, then the factor of time shows itself, first in the establishment of anaerobic activities with the exhaustion of oxygen; and, secondly, in the degree to which "putrefaction" proceeds.

CAUTION NECESSARY

Where the dissolved oxygen content of the water in the middle or lower reaches of a river at times of low stream flow is about

one-half of the difference between the saturation value and an assumed safe residual oxygen figure, the conclusion is not to be drawn that the sewage contributing population of a nearby city in the absence of sewage treatment may be doubled without producing a nuisance. The following factors need study:

1. The initial oxygen will not necessarily remain a constant. As the population increases in the upper valley the initial oxygen in the water of the middle and lower stretches may materially lessen.

2. Reaeration of the river water will not increase with the population. On the contrary, it is likely to decrease if the water surface is more or less covered with "sleek."

3. Sewage mud accumulates year after year at some places. It undergoes anaerobic decomposition and deoxygenates the overlying water to some extent.

In brief, the self-purifying power of streams may disappear quickly. The lower Passaic river, as described by Rafter and Baker, pages 58 and 579 of their book, is a striking example. In 1895 Jersey City still derived its water supply from the river at Belleville. In 1896 the Governor appointed a commission to recommend means of correcting the nuisances of this entire lower valley, due to the river having become an "open sewer."

RÉSUMÉ OF AMERICAN INVESTIGATIONS OF THE DILUTION METHOD

Notwithstanding the fact that within narrow limits it is now impracticable or inexpedient at this period of changing viewpoints to specify the degree of dilution that should obtain for a wide range of conditions, it by no means follows that American evidence is meager from the engineering standpoint. On the contrary, some of the most careful studies on sewage disposal are related to the dilution method.

Before the days of modern bacteriology the question was considered in Massachusetts for local needs, and English practice and viewpoints are discussed in early reports of the State Board of Health in a comprehensive way. These reports of Messrs. Folsom, Chesborough, Nichols and others were in some particulars less detailed than the studies conducted in connection with the sewage disposal problem of Chicago. The late Dr. John H. Rauch, Secretary of the Illinois State Board of Health, gave this

matter careful consideration with the aid of competent analysts, including Prof. John H. Long. Many valuable data are recorded in the early reports of that Board.

CHICAGO DRAINAGE AND WATER SUPPLY COMMISSION

We shall not attempt to exploit the historical side prior to the germ theory of disease and the establishment of bacteriology as a modern science, but shall begin with the comprehensive studies of American and European data by the Drainage and Water Supply Commission of Chicago, Ill., of which Mr. Rudolph Hering was Chief Engineer and Messrs. Benezette Williams and Samuel G. Artingstall were consulting engineers. These gentlemen made a report recommending the Chicago drainage canal in January, 1887. Their recommendations were predicated upon a degree of dilution equivalent to 4 cubic feet of lake water per second to be discharged into the canal for each thousand of population connected with the sewers. The essence of their conclusions with respect to this point are taken from pages 30–1 of their report in the following words:

RECOMMENDATIONS OF HERING, WILLIAMS AND ARTINGSTALL

The proper degree of sewage dilution in the new channel demanded a careful investigation. When sewage is mingled with a sufficiently large quantity of water it not only becomes inoffensive, but readily finds the oxygen which gradually purifies it. When the surface is covered with ice a greater dilution is necessary for this purpose than at other times when there is a constant replenishment of oxygen from the air. The proposed waterway should, of course, provide immunity from offense at all times.

The information upon which definitely to decide this question will be given in the final report, as the data have not yet been all collected, owing to the necessity of making actual tests of the oxidization of the canal water under the ice, which is being done for the use of the commission by Dr. J. H. Rauch, Secretary of the State Board of Health. The summer conditions are presented in his late report on the water supply and sewage disposal of Chicago. The result of these analyses will be compared with those of other streams that are also polluted with sewage in order to show the rate of oxidization with varying degrees of dilution and aeration.

For the purpose of estimating the cost of the water channel we have assumed 3600 square feet for the cross-section and a velocity of the water of 3 feet per second, or 2 miles per hour. This gives a discharge

of 600,000 cubic feet of water per minute, or 24,000 cubic feet for each 100,000 persons, which we believe equal to the maximum requirements of a population of 2,500,000 people.

In the course of the legislative hearings and other preliminary steps required for the enactment of the proper laws, this degree of dilution became reduced to 3.33 cubic feet per second per thousand population.

This may be fairly considered the starting-point of the scientific application of the dilution method for sewage disposal. The final report of the Pure Water Commission at Chicago was never made on account of lack of funds, but fortunately we have on record a comprehensive synopsis of the facts and factors then considered. They appear under the modest title of "Notes on the Pollution of Streams" and were described by Mr. Rudolph Hering at the Memphis meeting of the American Public Health Association in 1887. They appear in full in Vol. XIII of the Transactions of that Association. Eliminating the introduction, of a general nature, Mr. Hering's paper is given in full, with side headings added by the author, as follows:

HERING'S REVIEW OF EVIDENCE IN 1887.

The question then arises, How much sewage should be permitted in such a case? In other words, what is the proper standard of purity to satisfy the various interests? This is the subject on which I endeavored to get some light in the Chicago investigations, but, as I said, the data are not complete.

Measure of Dilution.—The first point to settle is a proper measure for the permissible pollution. This is best assumed as being the quantity of water which can safely receive the drainage from a unit of population; in other words, the least number of cubic feet of water per minute which should flow down the stream for say every 1000 persons draining into the same.

By using this measure we eliminate the difficulties arising from a varying quantity of water consumption and dilution of sewage before reaching the stream. In England, the quantity of sewage ranges from 30 to 60 gallons per head; in America, from 50 to 150 gallons per head. But the quantity of refuse per inhabitant does not vary much. Where factories discharge considerable waste matter of a particular kind, or where large slaughtering establishments drain into the rivers, some additional allowance for them may be required, but otherwise the amount of waste matter per inhabitant will be pretty constant, and therefore convenient as a measure.

The problem then is, How much running water must we have to dilute the sewage from every 1000 persons in order to make it inoffensive, not objectionable to manufacturing interests, nor destructive to fish?

Standard Required.—The standard for inoffensiveness must of necessity be one of personal judgment and can only be approximate. The admissible sewage pollution of water used for manufacturing purposes depends on the particular industry, some mills requiring a much higher standard than others; and, unless in any particular case the nature of the industry is a governing element, we are again obliged to resort to personal judgment as to what is a fairly clean water for average cases. A standard of pollution which, thirdly, will prevent the destruction of fish depends upon the particular species which it is desired to retain. Yet, as we find fish living in sewage-polluted water which is sufficiently diluted to answer the first and second requirements, we can usually ignore this one, except in occasional instances, where it assumes special importance, and where special experiments will become necessary.

There are three ways in which we may get a solution of the problem from this point of view. In the first place, we can obtain a sample of the average sewage per inhabitant from a sewer, and mix it with enough water to make it what is believed would be unobjectionable, and thus determine the dilution. This method can be applied in small towns—not so well in large cities where the sewage varies in different sections, owing to different classes of population and manufactories.

In the second place, we can observe the gradual increasing pollution of a water-course, caused by the successive discharge of a number of sewers, and, after determining the point at which we find the condition of the river to have become objectionable, either to the senses or for use, we can measure the flow, and find the population which has drainage into it at this point.

It is usually difficult to get a satisfactory answer in this way, owing to the imperfect mixture of the sewage with the river water until they have run a long distance. It was intended, however, to make some observations on this point in Chicago, where the river serves as the main outfall sewer for the city, with the hope of fair results, notwithstanding the additional difficulties there encountered, due to the frequent but irregular stirring up of the sludge by the tugs and vessels. But, owing to want of funds, this, as well as other inquiries, has not been undertaken.

The third way in which we can throw light on the question is to observe the gradual so-called self-purification of polluted streams. On this subject, taking a little broader view than required for the above special purpose, I have the following notes to present:

It has been asserted in England by Drs. Miller, Odling and Letheby,

that organic matter of sewage is rapidly oxidized during the flow of a river into which it is discharged, and that if the dilution is at least twenty times the sewage will not only be made inoffensive, but be entirely destroyed within a "dozen miles or so." But the Rivers Pollution Commission of Great Britain, in 1878, after a careful direct investigation, prove that this assumption is altogether wrong so far as the rapidity of oxidation is concerned, and state that there is no river in England long enough to allow of a complete disappearance of sewage-matter discharged into it.

Scope of Process.—The main causes of the apparent disappearance of such matter are dilution, subsidence and oxidation. Let us consider them for a moment.

When sewage is discharged into a comparatively large volume of water, it becomes dispersed throughout the mass, and lost to sight and even to chemical tests if the dilution is great enough.

The measure of relative dilution can usually be ascertained by the mineral salts in solution, and, particularly, by the chlorine in common salt conveyed to the streams by the sewage, because they are not liable to undergo any change which would cause their disappearance.

Subsidence of the heavier organic and mineral matters of sewage has a marked influence in clarifying a polluted river. It is observed immediately below outfall sewers, and is caused by a reduction in the velocity of the sewage after emerging from them, which permits the suspended particles to deposit. This deposit of sludge continues to undergo decomposition until the matter is reduced to its inorganic components. During floods the increased velocity of the water stirs it up, mingles it with the earthy matter generally suspended in flood-waters and allows it to be again deposited at another place lower down the river, usually in a less objectionable condition than before. Factory refuse often contains chemical agents, such as lime, alum, and metallic salts, which precipitate much of the sewage matter, and thus tend to increase the amounts of deposits. Metallic oxides unite with the sulphureted hydrogen of decomposing sewage, and form insoluble compounds and harmless deposits.

Biological Decomposition.—Oxidation and total destruction of sewage matter by decomposition was for a long time thought to be the main cause for the clarification of polluted rivers. Today it is known to be but a minor cause, compared with dilution and subsidence; and if the sewage is discharged in a fresh condition into a stream of water, its destruction is in part due to fish and other aquatic animals. Some of the refuse from stockyards is disposed of, no doubt, in this way. Most of the sewage, however, is decomposed or oxidized, as it is usually termed, by the myriads of microscopic plants, microbes, or bacteria contained in both air and water, which at once seize upon the dead organic matter. It is true that chemical changes, not caused by life,

assist in converting the organic matter into simpler compounds, but their effect is comparatively insignificant.

The English River Pollution Commissioners state that sewage oxidation is more active in sunshine than in shade, and is almost arrested at night, and when the thermometer approaches the freezing-point, showing its dependence on the condition favorable to the lower orders of life. Since then it has been quite conclusively proven that the question of sewage oxidation in a polluted stream, or even in the soil of sewage farms is practically one of a sufficiency of microorganisms and of air and other conditions that sustain their life.

Direct Chemical Oxidation.—Dr. Dupre sterilized sewage, and kept it for weeks without the slightest change. By adding a little non-sterilized sewage, decomposition at once began. Mr. Warrington has found similar evidence. Dr. Emmich has shown that sterilized sewage, continuously aerated by sterilized air, did not oxidize perceptibly, nor purify itself at all.

If the aeration of rivers can be kept up to the highest practicable point, it would on a summer day offer the most favorable conditions for a disappearance of the organic matter.

Applying these facts, we can say that for purifying the sewage discharged into a river, oxidation can be depended upon only to a limited extent, because of the comparative slowness with which it takes place. Subsidence of the heavier matter tends to clarify it before it flows many miles; dilution with a sufficient quantity of clean water prevents an offensiveness almost at once; but oxidation requires many days under continuous aeration of the river.

Therefore, by examining the actual purification of polluted streams, and realizing that oxidation is a comparatively small factor, we are furnished with some evidence as to the proper dilution of sewage in the case under consideration, which cannot be far wrong, and may serve a useful purpose until more information is obtained.

The data which are now available are not many, because opportunities to establish the same on a large scale, which alone is of practical value, have seldom offered.

In our country instances are the Desplaines and Illinois rivers, receiving the sewage of Chicago; the Blackstone river in Massachusetts, with the sewage of Worcester and the Merrimac river in Massachusetts, with the sewage of Lowell and Lawrence. In Europe the most instructive case is the river Seine below Paris, at the time when it received all the sewage from that city. Other rivers are the Irwell, Mersey and Darwen in England, and the Oder, Isar, and Elbe in Germany.

It would be tedious to describe to you in detail the changes taking place in each case, and I will confine myself to some general remarks. Profiles were platted of some of these streams, showing their general descent, to indicate their relative facilities for oxidation, also the

average dry weather flow at all points, gradually augmented by the affluents. The results of the chemical analyses were platted at the respective points.

It was clearly shown how the increased dilution lowered the percentages of albuminoid and free ammonia almost in exact proportion to the increase of dilution, and that the apparent purification, which was often supposed to be due to oxidation, was due mostly to greater dilution.

Chicago Evidence.—The sewage of Chicago, mixed in a proportion of about one of sewage to four of lake water, or of 60 cubic feet per minute per 1000 persons, is pumped into a canal, and flows, without further increased dilution, for nearly 30 miles in about as many hours, and its condition, which is quite offensive, is not changed very much. Then it descends over several dams, mingles with the water of the Desplaines river, and within a few miles it is visibly improved. When, 45 miles below Chicago, it unites with the water of the Kankakee and forms the Illinois river, the water causes a dilution twice as great as that in the canal, and the river loses its offensiveness during the greater part of the year. At Peoria, 158 miles below Chicago, the sewage has a dilution of nearly three times that in the canal, and, except when ice has covered the stream for some time, no odor can be detected, and the water is even partly used for the city's supply. Here there is a flow of 170 cubic feet per minute for every 1000 persons draining into it.

Owing to the fact that the velocity in the canal is greater than that in the rivers at its two ends, deposits are formed in the Chicago river before entering the canal, and again in the Desplaines river after leaving it.

I will say that the analyses upon which these deductions are based were made under the direction of Dr. John H. Rauch, secretary of the State Board of Health of Illinois, and that the conclusions that in winter 180 cubic feet of water per minute per 1000 persons draining at Chicago would be sufficient to prevent objectionable conditions all along the river is originally his.

The Blackstone river, in Massachusetts, which is quite foul below Worcester, and receives much additional sewage on its way, becomes unobjectionable at ordinary times for all but potable purposes about 15 miles below the city, with a dilution at the rate of 140 cubic feet per 1000 persons draining into it, together with considerable manufacturing refuse, and after there has been a chance for complete subsidence and some oxidation due to a large number of dams.

In Paris the sewage of nearly 2,000,000 people was turned into the River Seine before the irrigation fields were put in operation. The organic matter in this sewage per inhabitant is, from the analysis, hardly one-half that of our sewage, because excrementitious matter was almost wholly excluded from the sewers. The dilution which rendered

the polluted river entirely inoffensive in summer was 60 cubic feet per 1000 people after a flow of 14 miles and after subsidence of the suspended matter had taken place.

If we reduce the recommendations of Dr. Miller and others, for England, as mentioned above, to our measures, we find that they believe a dilution of say 120 cubic feet of water per minute for 1000 persons to be sufficient to guard against offensiveness. But this recommendation probably applies to small cities not devoted to manufacturing.

Conclusions.—By comparing these results, and also those of the other rivers mentioned, we can observe much similarity and consistency, and, for the present, we may draw the following inference: Rivers not to be used for water-supplies, but to be inoffensive to communities residing a few miles below, to remain fit for ordinary manufacturing purposes, and to sustain the life of fish, may receive the sewage from 1000 persons for at least every 150 to 200 cubic feet of minimum flow per minute, supposing that natural subsidence of the heavier matter takes place immediately below the town discharging the sewage.

Where, for some reasons, it is necessary to dilute it at once so that it is quite inoffensive before subsidence, which cases are rare, a somewhat greater dilution may be required. Inasmuch as the flow governing the minimum dilution occurs in summer, no attention need usually be paid to the larger dilutions required in winter, because the natural flow of the water is much greater at such time.

Beyond the above limit it appears to be advisable, when arranging for a sewage disposal, to resort to its purification at once by land or other filtration, or by chemical precipitation, in order to prevent the river water from becoming objectionable to others.

It is to be hoped that more investigations will be made on this subject, so that the limits, which sometimes may be very important from an engineering and financial point of view, can be more closely drawn. While the above figures may be a useful guide in many instances, yet they are but empirical formulæ, to be used only by those who thoroughly understand the subject, and to be applied only in cases similar to those from which they were deduced.

MASSACHUSETTS EVIDENCE IN 1890

In Massachusetts, following the reorganization of the State Board of Health in 1886, there was instituted a well-planned set of investigations of the Massachusetts rivers from a combined engineering and analytical standpoint with the use of laboratory methods which were the best then available. These investigations have been continued until the present time. In 1890 when more than two years' observations had been taken a special

report on water supplies and sewage was issued. Part I is devoted to recording and describing the results obtained from various rivers and water supplies; while Part II is devoted to the work of the Lawrence Experiment Station on purification matters.

In Part I Mr. F. P. Stearns under the heading "Pollution and Self-purification of Streams," gives a second classical discussion on this subject. Mr. Stearns introduced the custom of estimating the amount of constituents contributed to sewers by each inhabitant per day and then estimated what would be the figures of the principal constituents when the dilution ranged within the limits ordinarily found in streams of varying degrees of pollution. This served to accentuate the importance of the free ammonia determination as a yard stick for measuring the pollution found in various bodies of water. No decisive conclusions are drawn, although the debatable limit according to his observations falls within the range of from 2.5 to 7.0 cubic feet per second per thousand population.

Among the interesting discussions by Mr. Stearns of Massachusetts conditions is the reference to the influence of certain aquatic plants. He states that from a health standpoint this is one mode of self-purification of streams even if the water is temporarily rendered obnoxious by the organisms which effect the change. We quote the substance of Mr. Stearns' report on the Pollution of Streams, Massachusetts State Board of Health Report, 1890, Part I, pages 785–93. We have expressed the chemical results in parts per million rather than in parts per 100,000 and have added a few side headings.

STEARNS' SUMMARY ON THE POLLUTION OF STREAMS

There are many instances in which sewage is discharged into a stream without producing a degree of pollution which is apparent to the senses, or which is seriously objectionable where the stream is not used for the purposes of domestic water supply. On the other hand, it frequently happens that a stream receives so much sewage that it becomes very foul and offensive to those living near it.

The dividing line between these two conditions must always remain somewhat indefinite, both on account of a difference of opinion as to what degree of pollution is permissible, and because of the great difference in the conditions at different places, such as, for instance, the character of the sewage; the fluctuations in the flow of the stream,

occasioned by its use for mill purposes; the existence of mill ponds in which sewage deposits may accumulate; and the presence of population along the banks below the point where the sewage is discharged. At the present time the dividing line is rendered still more indefinite by a lack of information as to the effect of a given quantity of sewage upon a given quantity of water.

The investigation of the rivers in Massachusetts furnishes some information upon this subject, which will be presented in this section.

There are some instances in which the polluting matter from factories is more important in its visible effect upon a stream than domestic sewage; but in a great majority of cases, where the population is provided with sewers discharging into a stream, the domestic sewage is the controlling factor. In attempting to determine the permissible ratio between the amount of sewage and water, we are confronted by another trouble; namely, the variable amount of polluting matter contained in sewage from different communities; but, as this is due to the different amounts of water used in different places rather than to variations in the amount of polluting matter contributed per person, this difficulty will be avoided if we adopt as a basis for calculations the relation of the population to the quantity of water flowing in the stream. The volume flowing in streams is commonly expressed in cubic feet per second; but, in adopting this as a unit, it is necessary, in order to avoid too small quantities, to make the unit of population 1000.

The quantity of water which will dilute the sewage of 1000 persons sufficiently to render it unobjectionable for all purposes except drinking can be determined by two methods; first, by actual experience in the discharge of sewage into streams, where the population connected with the sewers and the volume of water flowing in the stream are known; and, second, by determining by chemical analysis the composition of the water of a stream which has been polluted by sewage to the greatest permissible extent, and then determining by calculation what relation of population to volume of water will produce the same composition.

The effect which the sewage of a given population may be expected to produce upon the composition of the water into which it is discharged will be understood best if the second method is first discussed. In order to make the calculations there referred to, it is necessary to know the actual amount of one or more constituents contributed to sewage per inhabitant, which can be determined best from analyses of sewage where the contributing population and the quantity of sewage are known, together with the corresponding analysis of the water supply which by the pollution became sewage. . . .

Standard Sewage.—Making an average of the above by allowing the observations at London and Lawrence full weight, and those at Worcester half weight, the quantities given below are obtained, which may be

adopted, for further calculations, as the standard amounts of each of these constituents contributed daily per inhabitant to change water into sewage:

Free ammonia	*Albuminoid ammonia*	*Dissolved solids*	*Chlorine*
.015 lb.	.003 lb.	.218 lb.	.042 lb.

Using these figures (See Table 2) as a basis, we may determine the parts per million of each of these constituents added to water to make sewage of different degrees of dilution. In most cases the amount of each originally contained in the water is so small that it may be neglected, in which case the calculated quantity will represent the actual composition of the sewage.

TABLE 43.—CALCULATED COMPOSITION OF SEWAGE OF DIFFERENT DEGREES OF DILUTION

(Parts per Million)

Volume of water per capital gallons daily.	Ammonia		Dissolved solids	Chlorine
	Free	Albuminoid		
40	45.0	9.0	654.0	126.0
50	36.0	7.2	523.0	101.0
60	30.0	6.0	453.0	84.0
70	25.7	5.2	374.0	72.0
80	22.5	4.5	327.0	63.0
90	20.0	4.0	291.0	56.0
100	18.0	3.6	262.0	50.0
120	15.0	3.0	218.0	42.0
150	12.0	2.4	174.0	34.0

If the above table is continued so as to include much greater degrees of dilution, then we have presented the conditions which obtain when sewage is discharged into streams. In this case, however, as the dilution becomes greater and the effect of the polluting matters of the sewage less and less marked, it becomes more necessary to take into account the original composition of the water with which the sewage is mingled. In addition to this no allowance is made for the loss of free and albuminoid ammonia, which sometimes takes place when sewage is highly diluted, as will be shown subsequently.

TABLE 44.—AMOUNTS OF AMMONIA, DISSOLVED SOLIDS AND CHLORINE ADDED TO STREAMS BY DOMESTIC SEWAGE FOR VARIOUS RATIOS OF POPULATION TO QUANTITY OF WATER FLOWING

(Parts per Million)

Volume of water		Ammonia		Dissolved solids	Chlorine
Cubic feet per second per 1000 persons	Gallons per capita per day	Free	Albuminoid		
0.5	323	5.580	1.114	81.0	15.6
1.0	646	2.790	0.557	40.5	7.8
1.5	969	1.860	0.371	27.0	5.2
2.0	1,292	1.395	0.278	20.2	3.9
2.5	1,615	1.116	0.223	16.2	3.1
3.0	1,938	0.930	0.186	13.5	2.6
4.0	2,584	0.697	0.139	10.1	1.9
5.0	3,230	0.558	0.111	8.1	1.6
6.0	3,876	0.465	0.093	6.7	1.3
7.0	4,522	0.399	0.080	5.8	1.1
8.0	5,168	0.349	0.070	5.1	1.0
9.0	5,814	0.310	0.062	4.5	0.9
10.0	6,463	0.279	0.056	4.0	0.8
15.0	9,694	0.186	0.037	2.7	0.5
20.0	12,926	0.139	0.028	2.0	0.4
30.0	19,389	0.093	0.019	1.3	0.3
40.0	25,852	0.070	0.014	1.0	0.2
50.0	32,315	0.056	0.011	0.8	0.2
100.0	64,630	0.028	0.006	0.4	0.1

Free Ammonia Index.—In order to make practical use of this table in determining the greatest amount of domestic sewage which can be turned into a stream without making it offensive, it is necessary to compare the calculated analyses of the table with observed analyses of polluted streams. In making such comparisons, the free ammonia, which is the characteristic feature of sewage, and which is found only in extremely small quantities in unpolluted streams, is the best index.

The Blackstone river, a short distance below the point where it receives the sewage of Worcester, contained on an average during the two years ending June 1, 1889, 2.160 parts per million of free ammonia. The stream at this place is very foul and offensive. At Uxbridge, 16

miles further down stream, where the sewage is further diluted to a considerable extent by cleaner water from the tributaries, the average free ammonia was 1.011. The water at this place is so much polluted as to affect its quality for manufacturing purposes, but it is not generally offensive to those living on the banks of the stream. At Millville, in the town of Blackstone, still further down stream, where the dilution is still greater, the average free ammonia is 0.455, and the river is inoffensive. The odor of the water, however, when a sample is agitated in a bottle, as observed by the chemist, is generally musty and disagreeable, and on a few occasions offensive. The free ammonia at this place was at one time as high as 0.896.

Stacy's brook in Swampscott, during the time of its examination, received much sewage from the easterly portion of Lynn, and contained on an average 1.858 parts per million of free ammonia. The stream has a foul appearance, and the samples generally had an offensive odor even during those portions of the year when, on account of the high flow, the free ammonia was considerably less than the average above given.

A single sample from Pegan brook, Natick, collected in June, 1889, and having 1.200 parts of free ammonia, was characterized by the chemist as having a distinctly musty odor when cold, and a strongly musty and disagreeable odor when hot.

Samples taken in September, 1888, from Coachlace brook in Clinton, which is a very foul stream, had an average free ammonia of 1.955 and an offensive odor. The pollution of this stream is partly by sewage and partly by wool-washing refuse. At the same time four samples were taken from the mouth of the south branch of the Nashua river, below Coachlace brook, which had an average free ammonia of 0.264. The odor of the samples was faint, and the river did not have a noticeable odor when the samples were collected. In one of the samples the free ammonia was 0.444.

Two samples collected from the Charles river, below Milford, where it is a very small stream, one taken a week later than the other, in July, 1890, contained respectively 1.570 and 1.320 parts of free ammonia. The first had only a faint odor, and the second was decidedly offensive. This case is introduced in part, for the purpose of showing that the amount of ammonia is by no means an unfailing index of the amount of odor from sewage. It is, however, the best index that we have where the pollution is occasioned by domestic sewage.

Several instances might be enumerated of streams which are polluted by sewage so that the water contains from 0.100 to 0.300 part of free ammonia, without having offensive odors.

Tentative Conclusions.—It will be seen that the foregoing data are insufficient for reaching a definite conclusion, and a further study of the subject is very much needed. In the meantime, however, it is necessary to solve practical problems, and it is therefore desirable to

limit the debatable ground as far as may be justified by the observations. For this purpose, two lines have been drawn across Table 44 to include those ratios of population to volume concerning which there may be doubt. These lines include volumes from 2.5 to 7.0 cubic feet per second per 1000 persons, and free ammonia from 0.399 to 1.116.

With smaller volumes of water, the pollution is so great as to be inadmissible. With larger volumes, the pollution is so small as to be clearly admissible from the standpoint of the offensiveness of the water. From other standpoints, however, such as the use of water for certain manufacturing purposes, the amount of dilution should be greater; and in a stream used for domestic water supply it cannot be said, with our present knowledge, that any degree of dilution will make the water entirely safe for use.

Influence of Deposits.—All of the foregoing relates to the pollution of the water itself, as if the sewage emptied into a stream of unvarying volume, flowing with sufficient rapidity to prevent deposits. If, instead, the sewage is turned into a stream where it is ponded by a dam, or if there are ponds on the stream below the point of discharge, the solid particles of the sewage may accumulate and decompose, giving off offensive gases. This is more likely to occur if the deposits are covered with foul water in which the dissolved oxygen has been used up, because the decomposition will then be putrefactive rather than a process of oxidation. The fluctuations in the height of a stream, where they cause large areas to be alternately covered with water, and left bare, are also unfavorable for the proper disposal of sewage. In short, there are many things, such as the variations in the volume flowing in a stream occasioned by its use for mill purposes, the amount and character of manufacturing wastes, and the subsequent use of the water for different kinds of manufacturing, which require careful consideration in each case, and often a considerable variation from any general rules which may be laid down.

Field Observations.—The other method of determining the ratio of population to flow of streams, referred to in the early part of this section of the report, depends upon observations of the effect of discharging the sewage of a given population into a stream of known size. In this State there are but two streams where a comparison of this kind is practicable; namely, the Blackstone and Merrimac rivers. The former has discharged into it the sewage of the city of Worcester, with an estimated population, in 1888, of 76,500. The total population above the point where samples were collected was at the same time 77,500. The volume of water flowing in the river during working hours was determined, but not the total quantity flowing in the whole 24 hours.

In order to obtain the latter quantity, which is needed for these comparisons, it is necessary to make use of the flow per square mile of drainage area, as determined by the actual measurement of the flow of

some other stream having a known drainage area. The Sudbury river measurements for the period under consideration are the most applicable to this case.

The average flow of the Blackstone river for the period under consideration, reckoned upon this basis, was 122 cubic feet per second; and, if we assume that the river received the sewage of 70,000 of the population, then the volume per 1000 persons would be 1.77 cubic feet per second. The amount of pollution at this place, as already stated, is much greater than is permissible. At Uxbridge, which is 16 miles further down stream, the flow upon the basis above given is 279 cubic feet per second; and, if we assume that the sewage of 3000 persons enters the river between Worcester and Uxbridge, making a total of 73,000, the volume flowing per 1000 persons was 3.88 cubic feet per second. The water at Uxbridge was so much polluted that its quality for manufacturing purposes was affected, but it was not generally offensive to those living upon the banks of the stream. The amount of pollution at this place was increased somewhat by the manufacturing refuse turned into the river below Worcester.

The Merrimac river will be considered with reference to the effect of the sewage of Lowell upon it. In this case observations for more than three years are available. The average flow of the river has been 8720 cubic feet per second, and the average population of Lowell for the same time 74,500; hence the volume flowing has equalled 117 cubic feet per second, per 1000 persons. If, instead of the average flow, we take the low-water flow of 2200 cubic feet per second, and the population as given by the census of 1890, the volume per 1000 persons is 28 cubic feet per second. It will be observed that the former of these results represents a greater dilution than any indicated by Table 44, while the latter shows a dilution four times as great as the highest about which there is any doubt. The discharge of this sewage into the river, added to that which has already entered it from cities and towns above, together with a vast amount of manufacturing sewage, has not affected the water enough to prevent the city of Lawrence, 10 miles below, from adopting and maintaining a water supply from this source; although the danger to health which has been found to exist in this water supply has led the city authorities to contemplate the introduction of water from a new source. This is a striking instance of the extent to which a great river can dilute the sewage of a very large population; but the fact that the water is not worse than it is, is undoubtedly due in part to the so-called self-purifying power of streams.

OHIO INVESTIGATIONS IN 1897-98

The third important investigation of American rivers was conducted by the Ohio State Board of Health in 1897–98. On

the question of stream pollution the report of Mr. Allen Hazen is particularly instructive in its terse descriptions of the factors observed in a number of the Ohio streams of varying size and with varying degree of pollution. The substance of his report is as follows:

HAZEN'S OHIO REPORT OF 1898

Sewage Disposal.—The question of sewage disposal must be regarded from two entirely different standpoints, namely, from the standpoint of water supply and from that of local nuisance. I shall take up first the question of local nuisance, and afterward, the bearing upon water supply.

Local Nuisance.—When sewage is discharged into a stream it may cause local nuisance in either or all of several ways. (1) It may deposit its suspended matters, forming banks of sewage mud which putrefy and give rise to offensive odors, are unsightly in appearance when exposed, and may obstruct the channel; or (2) the whole body of water into which sewage is drained may be rendered foul and of objectionable odor; or (3) floating particles of grease and other matters may be deposited on various shores and thereby cause offense.

The formation of sewage mud takes place principally in sluggish streams or in mill ponds, and will take place without much reference to the relative volumes of sewage and stream flow. If, however, the quantity of sewage is not large, and especially if the stream is subject to considerable floods, the deposits may not sufficiently accumulate to cause serious nuisance between the periods when the bed is reasonably well scoured out by flood flows.

Some streams are so sluggish that their beds are never scoured out, or only at intervals of some years, and such streams are especially liable to become offensive when sewage is discharged into them. The nuisance caused by floating particles is also largely dependent upon the character of the stream, and is usually less serious than the formation of deposits.

The putrefaction of the water of a stream as a whole results from the discharge into it of more polluting matters than can be oxidized by the dissolved oxygen in the water of the stream, and that which is absorbed before the water becomes objectionable. Sewage can be discharged into a stream up to the point where the greater part of the dissolved oxygen is removed without creating serious nuisance in this way. As long as the oxygen is everywhere in excess the organic matters in the sewage are more or less rapidly oxidized and destroyed without the formation of injurious products. When the quantity of sewage becomes so great that there is no longer oxygen enough to take care of all the matters requiring it, a part of the matters decomposes in the absence

of oxygen and with the formation of sulphureted hydrogen, carbureted hydrogen and other gases of powerful and disagreeable odors.

The amount of sewage which a given stream can receive without being overtaxed depends somewhat upon the amount of polluting material in the water before sewage is added. A pure mountain stream will carry more sewage without showing it than will a stream already considerably polluted, although as yet unobjectionable. It also depends somewhat upon the rapidity of the flow, a stream having a rapid flow and fall having better opportunities for the absorption of oxygen than a sluggish stream.

Degree of Dilution.—The quantity of water required to dilute the sewage from a given population so that no nuisance will be created is commonly stated at from 1.5 to 4 cubic feet of water per second per thousand of population. In the case of sluggish streams, or of streams the waters of which are already somewhat polluted, the quantity required for proper dilution may be increased to 6, 8 or even 10 cubic feet per second per thousand of population.

The flow of water from streams like those in Ohio in times of drought is frequently as low as 0.1 cubic foot per second per square mile of drainage area, and may occasionally be much less. With this quantity of run off, and with the smallest suitable amount of dilution, a stream would be required to have a drainage area of from 15 to 40 square miles for every thousand inhabitants, to properly dilute the sewage without creating a local nuisance. An inspection of the areas and populations makes it apparent that very many streams are so small that cities and towns upon them will find it necessary to seek other methods of disposal than the simple discharge of crude sewage, in order to prevent the creation of local nuisances in the streams below.

Those cities and towns having less than 15 square miles of drainage area per thousand of population are grouped together, and those having from 15 to 70 square miles are grouped together, 15 miles being taken as the smallest possible drainage area per thousand to give sufficient dilution to prevent local nuisance, with the climatic and geological conditions of the State of Ohio.

This limit was reached as much by an inspection of the tabulated areas and populations in connection with the known conditions of certain streams of the state as from theoretical considerations, and the same is true of the limit of 70 square miles. It must, of course, be borne in mind that in preparing this summary no account is taken of the different physical conditions of the beds of the streams below the points of discharge, nor of the different conditions with respect to maintaining large minimum stream flows. These conditions have not been considered because of inadequate data. Such data can be secured by more extended and minute examinations.

Advisability of Disposal Works.—The question as to the necessity

or advisability of establishing sewage disposal works is also dependent upon the population living in the immediate neighborhood of the stream below the point of sewage discharge and the damage which they suffer by reason of it. The extent of the damage resulting from stream pollution must be considered in connection with the cost of purifying sewage, and the question must be settled as to whether or not the inconveniences suffered are sufficient to justify the expenditures required for sewage purification.

The odors arising from a sewage polluted stream may be, in a broad sense, unhealthy, but as far as known, under ordinary conditions they do not directly cause serious disease, but are principally objectionable because of their disagreeable qualities. It is a serious question whether the purification of the sewage of a city, involving large expenditures of money, is warranted, if the most serious damage which can be shown to result from its discharge untreated is the occasional production of slight or moderate odors at points where they can affect only a scattered population below the outfall.

Without attempting to draw any general conclusions, it will be readily seen that the damage caused by a given amount of pollution and the resulting fermentation and evolution of offensive smelling gas depends very largely upon the character of the country through which the stream flows below the point of sewage discharge. In view of these and other conditions the summary given must not be taken as a final statement of the necessity of sewage disposal in Ohio, but rather as a provisional classification for aid in further study.

Sewage Disposal with Reference to Water Supply.—One of the most serious questions presented is the discharge of sewage into streams above points where those streams are used for public water supplies. At the present time in the State of Ohio, with very few exceptions river waters are used by cities and towns only in their raw state. The use of water taken from such rivers mixed with sewage is an unhealthy and highly objectionable habit.

Two ways suggest themselves for correcting this condition; to purify the sewage before it is discharged into the streams, or to purify the water before supplying it to the cities. From the standpoint of any particular city, the latter is the more efficient method, but the other is worth considering, especially if other objects are accomplished at the same time. With some European rivers the purification of both sewage and of river water is insisted upon, thus giving a double line of protection, which is certainly advisable in cases of very dense populations upon watersheds.

This problem must be considered, not only with reference to water supplies now taken from streams, but also with reference to those cities which may ultimately find themselves compelled to use river waters, although not at present so supplied.

MASSACHUSETTS DATA OF 1902

The next important report was that made by the Massachusetts State Board of Health in 1902 in accordance with a special act of the Legislature directing an examination of the various sewer outlets in the State and the effect of the same. Mr. X. H. Goodnough, Chief Engineer, presented a valuable report found on pages 283–452 of the Report of the Board for the year 1902. It is divided into two parts, the first dealing with sewer outlets along the sea coast, and the second, those discharging into inland waters.

The report is more particularly an engineering one, but also contains a record and brief interpretation of chemical and biological analyses. Instructive reading will be found as to the condition of sewer outlets along the various important rivers and their tributaries. The chief value of the report, however, is in the conclusion that objectionable conditions were found in all cases where the stream flow was less than 3.5 cubic feet per second per 1000 persons connected with the sewers and that the conditions are not likely to be objectionable where the dilution exceeds about 6 cubic feet. The last three or four pages of Mr. Goodnough's report are highly instructive and are quoted, as follows:

GOODNOUGH'S MASSACHUSETTS REPORT OF 1902

The results of the examinations show that sewage may be discharged into a stream without creating objectionable conditions, unless the water of the stream is used for water supply purposes or for certain manufacturing or mechanical purposes, if the flow of the stream is sufficient to dilute the sewage thoroughly, and provided also that the sewage be discharged into the stream through a properly constructed outlet.

In making the investigations of the effect of sewage disposal, information has been collected to determine as closely as practicable the relation that the quantity of sewage discharged into the various streams bears to the flow of the streams at the points of pollution, and the results are presented in Table 45.

As has already been shown, there is a wide variation in the flow of streams in different seasons of the year, the period of greatest flow being in the winter and spring, from December until May; and the period of least flow being in summer and autumn, from June to November. Since there is comparatively little variation in the quantity of putrescible organic matter discharged in the sewage from a given population in

TABLE 45.—SEWAGE DILUTION IN MASSACHUSETTS RIVERS

Name of stream	Watershed (square miles)	Estimated dry-weather flow (cubic feet per second)	Population discharging sewage into stream within a short distance of the point indicated	Flow per 1000 persons discharging sewage (cubic feet per second)	Total population discharging sewage into river above point indicated
Connecticut river, below Northampton and Easthampton	8,539	3,500	21,500	162.8	48,000
Chicopee river, at Indian Orchard	696	209	3,000	69.7	15,250
Quaboag river, at Palmer	213	73	1,200	60.8	2,950
Connecticut river, below Holyoke, including Northampton and Easthampton	8,627	3,535	66,000	53.6	91,000
Connecticut river, below Springfield, including cities and towns within 30 miles above	9,922	3,970	144,000	27.6	198,000
Merrimac river, below Lowell, excluding all other cities and towns	4,622	2,265	95,000	23.8	.....
Merrimac river, above Lowell, including Concord, Manchester and Nashua, N. H.	4,127	2,022	90,000	22.5	129,000
Chicopee river, at Chicopee	730	219	10,000[1]	21.9	27,150
Miller's river, at Athol	282	102	5,000	20.4	8,700
Merrimac river, below Lawrence, including Lowell	4,828	2,363	160,000	14.8	.....
Miller's river, at Orange, inlcuding Athol	322	116	8,000	14.5	11,700
Housatonic river, at Dalton	55	16	1,200	13.3	1,700
Merrimac river, below Haverhill, including cities and towns within 30 miles above	4,882	2,392	190,000	12.6	348,000
Westfield river, at Westfield	455	123	10,000	12.3	10,800
Merrimac river, below Lowell, including Concord, Manchester and Nashua, N. H.	4,622	2,265	185,000	12.2	.....

[1] Not including those discharging sewage through main sewer outlet at mouth of river

TABLE 45.—SEWAGE DILUTION IN MASSACHUSETTS RIVERS.—*Concluded*

Name of stream	Watershed (square miles)	Estimated dry-weather flow (cubic feet per second)	Population discharging sewage into stream within a short distance of the point indicated	Flow per 1000 persons discharging sewage (cubic feet per second)	Total population discharging sewage into river above point indicated
Ware river, at Ware	192	60	6,000	10.0	8,000
French river, at Webster	93	50	7,200	6.9	7,430
Taunton river, at Taunton	351	158	25,000	6.3	29,915
Nemasket river, at Middleborough	59	15	3,000	5.0	3,000
Fort river, at Amherst	41	10	2,000	5.0	2,000
Manhan river, at Easthampton	70	18	4,000	4.5	4,000
Green river, at Greenfield	90	23	6,000	3.8	6,000
Ten Mile river, at Attleborough	21	8	3,000	2.7	6,900
Housatonic river at Pittsfield	129	43	20,000[1]	2.1	21,700
Hoosick river, at Williamstown, including North Adams	177	46	25,000	1.8	29,775
Charles river, at Milford	11	3	2,000	1.5	2,000
Hoosick river, at North Adams	119	32	23,000	1.4	27,775
Broad brook, at Easthampton	12	4	3,000	1.3	3,000
North Branch, Nashua river, below Leominster, including Fitchburg	95	38	36,000	1.1	36,500
North Branch, Nashua river, at Fitchburg	62	25	28,000	0.9	28,500
Mill river, at Northampton	55	14	17,500	0.8	18,000
Monoosnock brook, at Leominster	11	5	7,000	0.7	7,000

[1] Previous to the introduction of sewage purification works.

different seasons of the year, the effect of the sewage upon a stream is greatest in summer, when the flow is least, and when the other conditions are most favorable for the development of offensive odors and objectionable conditions.

The flow of some of the streams of Massachusetts, as already indicated,

has been carefully measured for many years, and from these measurements the average flow of these streams in the drier portion of the year can readily be determined. In the cases of other streams polluted by sewage, measurements of the flow have been made from time to time; and from the results of these observations, taken in connection with the information now available as to the areas of the watersheds and as to the quantity of water held in storage in reservoirs on the watersheds of these streams for the maintenance of the flow in dry weather, it is practicable to estimate quite closely their average flow in the drier portion of the year.

Referring to the flow of the Sudbury river, it will be seen that in nearly every year there is a period of very low flow in the summer season. In a few of the years this period is short, covering only one or two months, while in other years the period of very low flow continues for five and even six months. The longer periods of very low flow represent in general the most objectionable conditions under which sewage can be discharged into a stream, and if objectionable conditions do not appear in these periods, they will probably not appear in the short periods of somewhat lower flow. There are of course, many cases in which it is important to consider the conditions that may exist in periods of extreme low flow, even if they continue for only a few days or even hours, but objectionable conditions of this sort are usually local and do not affect the stream as a whole. From the measurements of the various streams and the other information available the dry-weather flow of the different streams has been estimated, and is presented in Table 45.

It would have been impracticable to make measurements of the sewage from all of the sewers of the different cities and towns discharging sewage into the streams. As already indicated, there are very great variations in the quantity and character of sewage discharged from the different cities and towns, on account of differences in the quantity of water used, the leakage into the sewers, the quantity of manufacturing wastes, etc., but in general it has been found that the quantity of putrescible organic matter discharged in the sewage of the different cities and towns is approximately proportional to the population connected with the sewers, unless the character of the sewage is greatly affected by manufacturing wastes.

Information has been collected to determine as nearly as possible the population discharging sewage directly into each of the rivers, and the results are presented in the table. In the third column is given the population discharging sewage into the stream within a short distance above the point indicated and the total population discharging sewage into the stream or its tributaries above the point indicated is given in the last column.

The various streams which are polluted by sewage have been arranged

in the order of the ratios of the dry-weather flow of the stream to each 1000 of the population discharging sewage into the stream immediately above the point indicated. No account is taken in this ratio of the effect of sewage discharged into the stream at a considerable distance above the point indicated, although in some cases the effect of such pollution upon the water of the stream has not disappeared. Some of the rivers, such as the Deerfield, which is very slightly affected by sewage, and the Blackstone and Neponset, which are grossly polluted, have not been included in the table, and others have been omitted in cases where definite data are lacking.

It will be seen that at the top of the list are those streams in which objectionable conditions have not been found, excepting in cases where local nuisances exist by reason of an improperly located sewer outlet. The first case in the table in which the water of a stream is rendered generally objectionable by pollution is that of the French river at Webster. At this place it will be found, by reference to the details of the examinations of this stream, that the quantities of manufacturing wastes from wool scouring and cloth washing discharged into the stream are so great that the effect of the sewage alone is not determinable.

The sewage of the city of Taunton is being discharged into the Taunton river temporarily, pending the completion of the works and the installation of a sewage purification system. It does not appear that the river is badly polluted, except in the neighborhood of the sewer outlet at the present time.

The Nemasket river below Middleborough has been the subject of serious complaint, and the Green river at Greenfield has been objectionable in dry weather. The Fort river at Amherst flows through an uninhabited region for a long distance below the sewer outlet, so that attention has not been directed to the condition of the stream. The Manhan river has not thus far been made seriously objectionable by the Easthampton sewage, evidently on account of the fact that this sewage is discharged into a large pond, through which it flows before entering the river.

Conclusion.—The results of the investigations show that where the quantity of water available for the dilution of the sewage in a stream exceeds about 6 cubic feet per second per 1000 persons discharging sewage, objectionable conditions are unlikely to result from the gross pollution of all the water of a stream in dry weather. Under favorable circumstances, such as in cases where the sewage is discharged at many outlets into a large body of water, objectionable conditions may not result where the dilution is somewhat less than 6 cubic feet per second per 1000 persons; but objectionable conditions have resulted in all of the cases thus far examined where the flow has been less than 3.5 cubic feet per second per 1000 persons discharging sewage into the stream.

CHICAGO DRAINAGE CANAL LITIGATION

One of the most important law suits and by far the most extensive piece of litigation involving sanitary science in its various aspects, resulted from the attempt of the State of Missouri to restrain the State of Illinois and the Chicago Sanitary District from operating the Chicago drainage canal. This case was instituted on Jan. 17, 1900, which was practically the date of placing the canal in regular operation. In many of its aspects the proposition related to differences between the city of St. Louis and the city of Chicago. It was an interstate proposition and the court of original jurisdiction was the United States Supreme Court.

Thousands of analyses and numerous expert opinions and reports were obtained on an elaborate scale by each party to the suit. Several hundred thousands of dollars were spent. A record occupying some 8000 printed pages was the result. Fortunately Mr. M. O. Leighton made a comprehensive digest of the testimony and with much success reduced it to a volume of about 355 printed pages. It is published as Water Supply and Irrigation Paper No. 194 of the Department of the Interior, United States Geological Survey.

For use in this lawsuit the Sanitary District of Chicago published a report on "Streams Examinations," giving the various chemical and biological data, not only of the drainage canal, but of the Illinois river system; the Mississippi river above the mouth of the Illinois at Grafton, near the Chain-of-Rocks a few miles above St. Louis (but below the mouth of the Missouri river and near the intake of the St. Louis water supply), and opposite Jefferson barracks below the St. Louis sewer outlets; and also of the Missouri river at Bellefontaine.

Fig. 5, on page 215 shows a map of the Illinois river with the principal streams and sampling stations in and around St. Louis. With some modifications it is copied from "Streams Examinations" above-mentioned.

The average results are given in Table 46 of numerous chemical and bacterial analyses of the waters of the Des Plaines, Illinois, Mississippi and Missouri rivers from January to June, 1900, which was the first six months of operation of the present Chicago drainage canal. These data form part of a summary testified to by Prof. E. O. Jordan.

TABLE 46—SELF-PURIFICATION IN THE CHICAGO DRAINAGE CANAL, THE DES PLAINES, ILLINOIS AND MISSISSIPPI RIVERS. JANUARY–JUNE, 1900

Station	Period of flow, days	Parts per million					Bacteria per cubic centimeter
		Chlorine	Free ammonia	Albuminoid ammonia	Nitrites	Nitrates	
Drainage canal, Kedzie avenue	.....	9.87	1.31	.499	.0296	.289	1,332,000
Illinois-Michigan canal, Bridgeport	.....	96.6	8.05	2.05	.0214	.074	631,000
Drainage canal at dam, Lockport	.....	12.7	1.33	.347	.0185	.118	1,167,000
Illinois-Michigan canal, Lockport	1.6	124.5	10.90	2.07	.013	.066	1,755,000
Des Plaines river, Joliet	1.7	41.5	4.22	.83	.021	.086	744,286
Illinois river, Morris	2.5	24.5	2.46	.60	.075	.424	455,000
Illinois river, Ottawa	3.4	15.3	1.55	.41	.197	.966	116,000
Illinois river, La Salle	.....	17.5	1.05	.43	.109	.979	94,000
Illinois river, Henry	5.3	13.3	.92	.38	.102	.800	64,200
Illinois river, Averyville	.....	13.5	.81	.37	.004	1.150	51,800
Illinois river, Wesley	.....	12.0	.56	.41	.083	1.030	36,800
Illinois river, Pekin	9.9	12.3	.70	.43	.060	.990	68,400
Illinois river, Havana	11.4	11.2	.60	.36	.065	.570	23,100
Illinois river, Beardstown	12.8	10.7	.69	.44	.106	.685	28,200
Illinois river, Kampsville	15.5	11.3	.66	.44	.044	.870	33,700
Illinois river, Grafton	17.7	9.8	.46	.42	.031	1.060	21,000
Mississippi river, Grafton	.....	5.3	.123	.522	.007	.300	30,600

TABLE 46.—SELF-PURIFICATION IN THE CHICAGO DRAINAGE CANAL, THE DES PLAINES, ILLINOIS AND MISSISSIPPI RIVERS. JANUARY–JUNE, 1900.—Concluded.

Station	Parts per million					Bacteria per cubic centimeter
	Chlorine	Free ammonia	Albuminoid ammonia	Nitrites	Nitrates	
Mississippi river, Alton:						
East bank	7.2	.242	.489	.0165	.69	30,300
East of center	5.8	.251	.509	.013	.65	47,000
Midstream	4.9	.224	.528	.01	.429	51,800
West of center	4.6	.194	.544	.0098	.396	55,200
West bank	4.3	.159	.495	.0102	.379	42,500
Missouri river, Fort Bellefontaine	15.4	.065	.754	.0066	.56	43,100
Mississippi river at Chain-of-Rocks:						
East bank	6.7	.211	.586	.0151	.58	36,200
Midstream	8.6	.145	.697	.0096	.43	46,600
Intake tower	10.3	.117	.679	.0845	.38	41,000
West bank	12.8	.081	.714	.0083	.46	49,700
St. Louis tap water	13.4	.028	.196	.0052	.4	7,760
Mississippi river, Jefferson Barracks:						
East bank	7.2	.263	.612	.016	.76	65,600
East of center	7.2	.285	.639	.015	.6	59,700
Midstream	8.4	.223	.607	.013	.565	69,500
West of center	11.3	.206	.647	.012	.53	74,800
West bank	12.6	.259	.608	.012	.48	69,900

The data for the new drainage canal are for the months of April to June, inclusive, and therefore are not directly comparable with the figures for the old Illinois-Michigan canal or for the rivers below. The period of flow of the water from Chicago to the Mississippi, a distance of about 357 miles, is for average conditions. At times of heavy floods this period probably is reduced by about one-half.

The findings were in favor of Illinois and Chicago on the basis that the evidence did not support at that time the allegations in the bill of complaint. As a contribution to sanitary science for the advancement of the art of sewage disposal, the return on the investment in this litigation was comparatively small. There are a number of facts along broad practical lines, however, that are demonstrated with clearness. In the author's opinion some of the more important features developed were the following:

1. The original jurisdiction of the United States Supreme Court in the matter of pollution of interstate rivers, unaffected by any special interstate treaties, was established.

2. In its decision in overruling the demurrer with respect to the jurisdiction of the court, it is intimated very plainly that an alleged nuisance must be made out upon determinate and satisfactory evidence and that the nuisance must not be doubtful and that the danger must be shown to be real and immediate. In brief it appears that the court approached this suit with the viewpoint that a restraining order could only follow in the event that an unmistakeable nuisance was created, whatever may be the law in other respects.

3. In this instance gross nuisances were substantially absent. In fact, odors and chemical evidence of pollution in the lower Illinois river were absent, comparatively speaking. They were certainly present to a much less extent than prevailed before the opening of the new canal. That is explained in part by the pollution from the Chicago sewage in earlier years entering the Illinois river through the old Illinois and Michigan canal, and partly by the industrial wastes, particularly at the cattle yards and distilleries at Peoria and vicinity. Missouri paid considerable attention to the question of sludge deposited at times of ordinary flow and flushed out at times of heavy floods. But even this did not carry strongly on account of more or less similar conditions prevailing in the upper Mississippi and Missouri rivers, to the latter

of which the residents of Missouri were contributors in the matter of sewage sludge.

4. For measuring the self-purification of the local streams in the absence of gross pollution to the sense of sight and smell, chemical analyses by the methods then in vogue were shown to be inadequate. In the muddy streams the soil wash contained amounts of albuminoid ammonia and oxygen consumed which went a long way toward disguising the effect of sewage pollution and made averages, as well as single analyses, uncertain and capricious. It accentuated with force the inability of the chemist to differentiate between organic matter of vegetable and animal origin.

5. Fish life in the Illinois river was measurably restored by the oxygen in the additional volumes of lake water brought into the lower valley through the new drainage canal in comparison with the almost nominal dilution in the old Illinois and Michigan canal. The question of putrescibility and stability of organic matter and more particularly the so-called oxygen balance received no substantial attention in this case.

6. Dissolved oxygen tests were made, however, in a few instances, showing that the atmospheric oxygen was not exhausted according to the limited data available at the foot of the drainage canal and that passage over the bear-trap dam brought the aeration from about 8 to 63 per cent. of saturation. In the lower stretches of the Illinois river where the slope is very flat, many growths of chlorophyl-bearing organisms occurred. It was learned that these organisms have the power of giving off oxygen to the extent of supersaturating the surface of quite highly polluted water. Turbidity seemed to obscure such growths in an irregular way.

7. The studies of the life history of disease-producing germs of the water-borne group doubtless constituted the most important scientific aspect of the case. In particular the work of Messrs. Jordan, Russell and Zeit showed with added strength the inability of typhoid fever germs to multiply in water, and emphasized the importance of bacterial antagonism in showing the rate of death of these germs in water. The more polluted waters carry a richer bacterial flora and more food, but a shorter life for typhoid germs was noted than was the case in the comparatively pure Lake Michigan water. The period of transit according to the stage of the water in the Illinois river and the volume of

lake water employed ranged from about 8 to 15 days. It was claimed by Missouri witnesses that some of the "resistant minority" among the intestinal germs entering the water wth the Chicago sewage, might readily pass from Chicago to the Mississippi river in the vicinity of St. Louis and enter the intake of the city water supply. Importance was attached to the effect of accumulations of sludge at times of dry weather with the subsequent scouring out of the sludge deposits at times of floods following heavy rains.

8. Missouri based its case largely upon the bacteriological proposition above stated, supplemented by the vital statistics of the city of St. Louis before and after the opening of the drainage canal. These statistics showed irregularities in classification and carried less weight than at first expected.

9. The court said in its decision a number of things of interest to the layman in addition to the need above mentioned for the nuisance complained of to be decisive in its nature. In particular did it refer to the well-established principle in suits of equity that the complainant must come to court with clean hands in respect to the matter or matters upon which he sought relief. Illinois naturally emphasized this point and repeatedly cited what Missouri cities, such as St. Louis and Kansas City, were doing toward polluting the water supply not only of Missouri communities, but also of those situated in the lower Mississippi valley.

10. But little attention was given by the court to the fact that geographically the city of Chicago is not naturally upon the watershed of the Mississippi river, but that its drainage was brought thereto through a canal cut through a low ridge separating Chicago from the watershed of the Desplaines river, the nearest tributary of the Mississippi river. Legally, that was a matter for the state of Illinois to adjust, and the State had authorized by due enactment of the Legislature the construction of this canal, and the diversion of lake water therefor had been recognized by a permit from the Secretary of War.

This decision was handed down by Mr. Justice Holmes on Feb. 19, 1906, and is to be found in 200 U. S., 496, and also at the end of Mr. Leighton's paper above mentioned.

HERING AND FULLER'S REPORT ON THE CHICAGO DRAINAGE CANAL IN 1906

In the autumn of 1906 Mr. Rudolph Hering and the author were appointed a committee to report to the International Waterways Commission concerning certain aspects of sewage disposal in the Chicago Sanitary District, and with especial reference to the construction of the Calumet branch of the drainage canal. The report was made under date of Dec. 18, 1906, and appears as an appendix to the Report on the Chicago Drainage Canal by the International Waterways Commission. The late autumn was not a particularly fortunate time for studying the conditions, but it appeared that a dilution of 3.33 cubic feet per second for each thousand of population was as low a figure as possible to use even with trade wastes eliminated. A summary of the observations and comparisons then made may be briefly quoted from page 45 of Document No. 293, 1907, of the United States War Department, as follows:

Summary.—The disposal of sewage by dilution depends on the amount of oxygen in the diluting water being sufficient to prevent putrefaction of the organic matter in the sewage as the latter undergoes bacterial decomposition. If the oxygen is deficient bacterial decomposition produces what is called "putrefaction," with its various attendant bad odors, such as noted for years in Chicago at "Bubbly Creek." If there is a sufficient amount of oxygen dissolved in the water to combine with this organic matter, decomposition goes on without any foul odors and the organic matter is reduced to inert matter in an inoffensive way.

This question is one of balancing the amount of oxygen in a given volume of water with the amount of decomposing organic matter in the sewage, which naturally must vary greatly.

There are many observations of more or less accuracy available to give figures for this relation. The Massachusetts State Board of Health made a special inquiry into this subject for all local rivers in 1902, with conclusions, stated on page 452 of their annual report for that year, as follows:

"The results of the investigations show that where the quantity of water available for the dilution of the sewage in a stream exceeds about 6 cubic feet per second per 1000 persons discharging sewage, objectionable conditions are unlikely to result from the gross pollution of all the water of a stream in dry weather. Under favorable circumstances, such as in cases where the sewage is discharged at many outlets into a large body of water, objectionable conditions may not result where the dilution is somewhat less than 6 cubic feet per second per 1000 persons but

objectionable conditions have resulted in all of the cases thus far examined where the flow has been less than 3.5 cubic feet per second per 1000 persons discharging sewage into the stream."

These conclusions apply for the most part to comparatively small streams into which much manufacturing waste is discharged and upon which millponds are situated.

There are times when the flow of water in the drainage canal appears to have been insufficient to eliminate objectionable odors entirely. How far this may be explained by confusion on the part of the observers of the putrefactive odors emanating from the Illinois and Michigan canal with those of the new canal, and how far it may be due to temporary reductions in the rate of flow in the new canal and river to facilitate construction work, and also to the effect of rainfalls and to old deposits in the South Fork, we are unable to say.

The new canal appears to serve at present about one-half the population for which it was designed, and through it flows a volume of lake water which is variable, but which averages not far from one-half of the ultimate quantity.

It is our judgment that for large canals with the trade wastes eliminated a dilution of 3.33 cubic feet per second for each 1000 population connected with the sewers, also receiving storm water, is as low a figure as it is now possible to state. Local conditions, especially temperature, which affects bacterial activities and the coefficient of absorption of oxygen by water, and still other matters, bear upon this question, the detailed discussion of which is not now necessary. We feel certain that a dilution of 2.5 cubic feet per second would cause offense at times, and probably also a dilution of 3 cubic feet per second.

SANITARY CONDITION OF MERRIMAC RIVER IN 1908

The Massachusetts Legislature of 1908 directed the State Board of Health to investigate the sanitary condition of the bed, banks and waters of the Merrimac river and tributaries thereof. At the end of the year the State Board of Health made a special report printed as a separate pamphlet of 40 pages which is full of interesting comments and comparisons. It is composed chiefly of the detailed report of the Chief Engineer of the Board, Mr. X. H. Goodnough. It figures the dry-weather dilution of sewage on the basis of the entire population above a given point rather than on the basis used in the 1902 report where the figures related to the sewage entering within a short distance of the point indicated. This reduced materially over the earlier figures of Table 45 the degree of dilution as will be noted from the following brief summary:

Point considered	Watershed (square miles)	Estimated dry-weather flow[1] (cubic feet per second)	Estimated population discharging sewage into stream[2]	Flow per 1000 persons discharging sewage (cubic feet per second)
Above Lowell.....	4,127	2,022	70,000	29.0
Below Lowell.....	4,636	2,318	182,300	12.7
Below Lawrence...	4,840	2,369	273,100	8.7
Below Haverhill...	4,898	2,384	315,500	7.6

[1] 0.50 cubic foot per second per square mile above Lawrence. 0.25 cubic foot per second per square mile below Lawrence.
[2] Including places above.

The report states unqualifiedly that there is no reason to doubt that when a stream is polluted by sewage to the extent of 3.4 cubic feet per second per thousand persons discharging into the stream, a nuisance will surely follow. At Webster on French river and at Taunton on Taunton river, trade wastes are a factor and show that the pollution has a marked effect upon the streams when the dilution is equivalent to about 5.8 cubic feet per second per thousand inhabitants. At Webster the French river is very dirty and is stated to have an offensive odor at times.

The dilutions in the lower Merrimac are intermediate between these instances cited and a dilution of 10.2 cubic feet per second per thousand people as found in the Westfield river at Westfield. Here manufacturing wastes are comparatively insignificant and the report states that the effect of sewage in the Westfield river is as yet comparatively slight except in the immediate neighborhood of the sewer outlet of the city of Westfield. In considerable detail discussion is given to manufacturing wastes, particularly from the wool scouring establishments along the Merrimac especially at Lawrence.

Although the Merrimac river water after filtration serves as an acceptable water supply for the city of Lawrence, it is made very plain that there are places where offensive conditons exist. In particular are these to be found below the discharge of wool scouring wastes and in the vicinity of those sewers which terminate some distance above the ordinary river edge. In some instances this is true where the sewers extend to the ordinary edge of the water, which at times recedes and exposes objectionable deposits.

From the analytical standpoint the quantity of albuminoid ammonia is stated as probably the most reliable index available

on the pollution of a stream, but that it is necessary to take into account other factors. This comment is perhaps associated more than would appear at first sight with the individuality of local conditions. Disregarding for the moment the effect of impounding by the dams at Lowell and Lawrence, it is safe to say that such a statement would not apply to the muddy waters of the Central West. However, for the Merrimac river, it is interesting to note the progressive increase in chemical constituents indicating sewage pollution, as shown by Table 47.

At times of very dry weather no water flows over the Lowell or Lawrence dams when the water is used for power purposes. Naturally the sewers which discharge into the comparatively dry stream bed above the foot of the power canals cause deposits which give off bad odors. In particular are the conditions offensive where wool scouring deposits are found. The odors are worst at places where the sewage flow stands in pools and decomposes during intervals between substantial flows of water over the dams. In this connection the dissolved oxygen content as shown in Table 42, page 221, is of interest.

Another feature of interest relates to the comments upon the sewage disposal systems on tributaries of the Merrimac river. At Andover it appears that the sewage from the low-lying districts of the town is not purified, apparently owing to the cost of pumping the sewage up to that portion of the system which delivers by gravity to the disposal works. The Westboro and Hudson works are also stated as not having given satisfactory results uniformly, partly through neglect and partly, in the instance of Hudson, through not conveying all of the sewage to the filtration area. As stated later, the intermittent sand filters of the Hudson disposal plant were at that time struggling with a severe burden from wool scouring wastes.

The report unmistakably shows the necessity of more careful attention to the disposal of sewage in the Merrimac valley. Hitherto this stream, originating in New Hampshire, has been exempt from the supervision of the State Board of Health, although following this report a recommendation was made to have its pollution put under control, although in a separate class from inland waters wholly located within the state. The situation is tersely summarized by the State Board in this special report and which summary appears also in their annual report of 1908, as follows:

TABLE 47.—CHEMICAL EXAMINATION OF WATER FROM THE MERRIMAC RIVER ABOVE LAWRENCE AVERAGES FOR SIX MONTHS, FROM JUNE TO NOVEMBER, INCLUSIVE (Parts per million)

Year	Color	Residue on evaporation		Ammonia				Chlorine	Nitrogen as		Oxygen consumed	Hardness
		Total	Loss on ignition	Free	Albuminoid				Nitrates	Nitrites		
					Total	Dissolved	Suspended					
1887	4.7	48.2	12.4	.027	.211	.....	.....	2.2	.097	.....	.....	.....
1888	3.2	36.4	11.3	.029	.197	.153	.044	1.8	.074	.003	.....	.....
1889	3.5	.....	.....	.047	.212	.176	.036	2.0	.053	.002	.....	.....
1890	3.7	42.7	15.6	.061	.187	.148	.039	1.9	.068	.002	.....	16.0
1891	2.1	40.6	13.7	.066	.179	.138	.041	2.1	.090	.002	.....	14.0
1892	4.6	42.5	15.0	.054	.186	.155	.031	1.9	.087	.002	.....	15.0
1893	4.0	42.5	16.2	.084	.172	.138	.034	2.3	.057	.003	5.2	13.0
1894	3.2	38.2	13.5	.086	.174	.142	.032	2.5	.043	.001	4.0	13.0
1895	5.2	44.5	19.7	.068	.251	.194	.057	3.0	.067	.003	6.0	15.0
1896	4.6	42.4	17.0	.100	.224	.181	.043	2.5	.067	.005	5.7	13.0
1897	5.8	40.6	16.7	.061	.222	.190	.032	2.1	.053	.002	5.3	10.0
1898	4.4	44.6	18.7	.076	.262	.208	.054	2.5	.050	.005	5.9	13.0
1899	2.4	44.2	15.7	.138	.277	.207	.070	3.2	.052	.004	4.3	13.0
1900	2.7	42.2	13.5	.126	.249	.190	.059	3.2	.050	.003	4.6	13.0
1901	4.4	47.3	19.0	.100	.280	.205	.075	2.8	.070	.006	6.5	15.0
1902	4.2	44.0	18.5	.110	.231	.180	.051	2.6	.038	.003	6.5	11.0
1903	3.7	46.6	17.3	.111	.226	.166	.060	3.1	.052	.005	6.4	14.0
1904	3.1	46.7	18.0	.211	.247	.169	.077	3.3	.053	.004	6.2	14.0
1905	4.4	49.2	20.1	.177	.242	.183	.059	3.8	.040	.005	7.4	12.0
1906	3.9	53.0	21.2	.170	.263	.215	.048	4.0	.027	.005	7.2	14.0
1907	4.0	49.2	18.0	.293	.253	.175	.078	4.1	.047	.005	5.9	13.0
1908	3.3	56.1	21.9	.354	.303	.196	.107	5.7	.052	.006	7.4	15.0

FINDINGS OF THE MASSACHUSETTS STATE BOARD OF HEALTH

In accordance with Chapter 114 of the Resolves of 1908, the State Board of Health makes the following report upon the sanitary condition of the bed, banks and waters of the Merrimac river and of the streams tributary thereto. No appropriation was made for the proposed investigation, and it has been made with the help of the general funds of the Board and those for the examination of sewer outlets, with the results contained in the appended report of the chief engineer of the Board. The facts therein are made a part of this report.

The river as it enters the state from New Hampshire has on its main line and branches received sewage from 180,000 people, together with large manufacturing wastes. The resulting pollution, as indicated by the amount of albuminoid ammonia, has in the past twenty years increased about 40 per cent.; but, as in the early years of this period the flow of water in the river was greater than usual and in the past few years has been less, ending with the driest year of the period, the actual increase in pollution is not as much as 40 per cent. The pollution of the river above Lawrence has in the same time increased at about the same rate. Above Haverhill observations are limited to the past ten years, in which the increase in percentage per year has been about the same as that above Lawrence.

For the past few years the pollution above Lawrence has been 35 per cent. more than that above Lowell, and the pollution above Haverhill has been 31 per cent. more than that above Lawrence, while the increase in passing Haverhill is about 7 per cent.

Farther down the river the water is less polluted, so that, entering the state with a certain amount of pollution, this pollution is, where greatest, increased about 90 per cent. by passing the cities of Lowell, Lawrence and Haverhill.

At present this stream of water is not in a condition to be injurious to the public health, and by proper regulation it may be kept many years, perhaps generations, free from danger.

There are, however, many localities in each of these cities, near the outlet of sewers, where the stream is locally polluted, the sewage not being disseminated through the stream; and where the bed and banks at night and on Sundays, when the mills are not running, and at low tide near the lower city, are exposed, coated with the refuse of sewage and of some manufacturing wastes. At these places the conditions are injurious to the health of those living or working near.

These conditions may be obviated in general by extending the sewer by an iron pipe, smaller than the sewer, but large enough to convey the ordinary sewage, to beyond the edge of the stream at the lowest stage and discharging under water, so that a clean stream of water may continually flow between the shore and the outlet. In this way the sewage

becomes diluted by the water into which it is discharged, and the shore is kept clean.

Of the manufacturing wastes, the most obvious and the one that causes the most complaint upon this river is that resulting from the scouring of wool. This process of washing and discharging the effluent containing large quantities of grease into the river results in a grease-covered shore and bed for a long distance down stream. The grease associates with and holds other objectionable matter, and, while we cannot say that it has up to this time been injurious or dangerous to the public health, it has become very disagreeable. The boatmen at Haverhill complain of the black grease adhering to their boats. It is at present a very disagreeable addition to the river, and may become injurious to the public health.

In other countries, and to some extent in this, the grease, which is the objectionable element in the effluent, is removed and made into valuable articles of commerce.

It would probably be no great hardship if the scourers of wool were required to keep the grease out of the river. If this were done the appearance of the river would be very much improved and the ground for much of the complaint in regard to its present condition removed.

WISNER'S REPORT ON THE CHICAGO DRAINAGE CANAL IN 1911

Liberal reference has already been made in this chapter to this excellent report dated Oct. 12, 1911. With the staff of the Chicago sewage testing station under the charge of Mr. Langdon Pearse data have been secured which in some ways are more valuable than those available elsewhere.

In particular is this so as to the oxygen content and stability of the canal waters, the influence of sewage sludge and the comments as to requirements for protecting fish life. The main conclusions have been cited already, but the entire report is worthy of most careful study.

Analytical data representing warm-weather conditions in the water at the foot of the canal are given as shown in Table 48:

TABLE 48.—RECORD OF DISSOLVED OXYGEN AND PUTRESCIBILITY AT THE POWER HOUSE OF THE SANITARY DISTRICT, LOCKPORT

1911 Date	Flow, cubic feet per minute per 1000 population	Dissolved oxygen		Putrescibility Relative stability number
		Parts per million	Per cent. saturation	
March 21.....	145.7	7.5	58	84
30.....	147.1	4.7	37	75
April 6.....	156.0	5.4	41	80
13.....	153.4	4.3	37	75
27.....	161.1	0.6	6	60
May 4.....	165.1	2.4	22	71
10.....	161.0	0.5	5	32
18.....	182.8	0.3	4	32
23.....	191.5	0.6	6	80
June 1.....	182.5	0.2	2	18
16.....	221.20	0.04	0.4	7
22.....	198.1	0.0	0	9
29.....	194.3	.....	.....	9
30.....	191.2	0.1	1	9
July 6.....	188.4	0.0	0	15
13.....	202.5	0.0	0	5
19.....	196.9	0.0	0	5
19.....	.....	0.0	0	4
20.....	195.6	0.0	0	6
28.....	201.7	0.0	0	5
Aug. 3.....	191.7	0.2	2	9
10.....	147.1	0.3	3	24
17.....	202.8	0.0	0	6
24.....	208.9	0.0	0	6
30.....	196.2	0.0	0	9
Sept. 14.....	188.4	0.0	0	9
21.....	201.1	0.0	0	8
28.....	188.4	0.1	1	9

Sewage Sludge.—In the main canal sludge is recorded as follows:

Small earth section.....	398,301 cubic yards
Full earth section	1,347,233 cubic yards
Rock section	0 cubic yards
Fore bay	592,800 cubic yards

The irregular distribution is due principally to velocities of flow as shown by Table 49:

TABLE 49.—HYDRAULIC PROPERTIES AND FILL IN MAIN CHANNEL

Station number	Nominal cross section in square feet.	Nominal flow depth in feet.	Velocity in nominal section in feet per second				Maximum fill			Average fill cubic yards per lineal foot.
			With flows in cubic feet per second				Area in square feet.	Per cent. original section	Cubic yards per lineal foot.	
			5000	6000	7000	8000				
46+00 to 456+62	3792	24	1.32	1.58	1.85	2.11	670	17.7	24.8	9.7
456+62 to 734+40	5990	24	0.84	1.00	1.17	1.33	1730	28.9	64.1	48.5
734+40 to 1505+00	3864	24	1.29	1.55	1.81	2.07	46[1] 934[2]	1.2 24.1	1.7 28.9	—0.58[4]
1505+00 to 1625+00	3570 to 11260	24.9 to 25.0	1.4 to 0.44	1.68 to 0.53	1.96 to 0.62	2.24 to 0.71	528[3] to 3770	10.2 to 33.4	19.6 to 140.0	49.4

[1] This figure is for the rock section proper.

[2] This figure is for the end of the rock section where it enlarges to make the forebay of the controlling works.

[3] Minimum fill is not at minimum section, but at section with 5160 square feet original area.

[4] This figure is negative because the rock section was originally cut below grade in places. The computations show a negative fill on the grades called for. In places a slight actual fill has occurred.

Analyses of this deposit are given in Table 50:

TABLE 50.—SUMMARY OF ANALYSES OF DEPOSITS IN MAIN CHANNEL

March to September, 1911

Sampling point	Date	Specific gravity	Moisture per cent.	Per cent. of dry			Remarks
				Volatile	Fixed	Organic nitrogen	
Kedzie avenue	Mar. 21	.....	20.1	6.3	93.7	0.12	
	May 10	1.71	35.4	9.2	90.9	0.18	N. bank.
	May 10	1.85	24.5	5.1	94.9	0.14	Middle and W.
	July 28	2.25	14.5	4.9	95.1	0.13	Many pebbles in mud.
Summit railroad bridge	July 28	2.02	20.4	3.5	96.5	0.11	Few pebbles.
Argo	Mar. 21	1.39	50.0	14.0	86.0	0.38	
Half mile below entrance of rock section	July 28	1.41	54.6	10.7	89.3	0.38	Tarry odor.
Lemont	Mar. 21	.....	71.6	24.0	76.0	0.56	
	July 28	1.38	57.2	13.3	86.7	0.38	Tarry odor
Controlling works	Mar. 21	1.10	76.6	31.0	69.0	0.96	
	July 28	1.38	56.3	17.1	82.9	0.54	Tarry odor.
Forebay first bridge	July 28	1.34	62.3	14.9	85.1	0.70	Tarry odor.
Forebay second bridge	July 28	1.38	55.8	15.2	84.8	0.58	Tarry odor.
Power house	Mar. 21	1.34	55.6	12.6	87.4	0.48	Tarry odor.

The most interesting thing here to note is the smaller per cent. of moisture and of organic volatile matter in the sludge from the upper than the lower sampling stations. This is explained by the septic action having eaten up much of the organic matter, leaving mineral deposits in the upper reaches. How far the sludge in the lower reaches may have been caused by gas-lifted particles having been moved from the upper part is not discussed.

Figs. 6 and 7 show views of the Chicago drainage canal, through the courtesy of Mr. Wisner.

THE SIGNIFICANCE OF FLORA AND FAUNA IN MAINTAINING THE PURITY OF NATURAL WATERS AND HOW THEY ARE AFFECTED BY DOMESTIC SEWAGE AND INDUSTRIAL WASTES

The late George W. Rafter was one of the first sanitary engineers in this country to look carefully into the life history of various microscopic growths regarding not only questions of

water supply, but also of sewage disposal in its relation to the self-purification of streams. He outlined the scope of this subject at some length in his discussion in 1891 of the paper by Dr. Currier on "The Self-Purification of Flowing Water." Mr. Rafter's discussion is found on page 70 of Volume XXIV of the *Transactions of the American Society of Civil Engineers.*

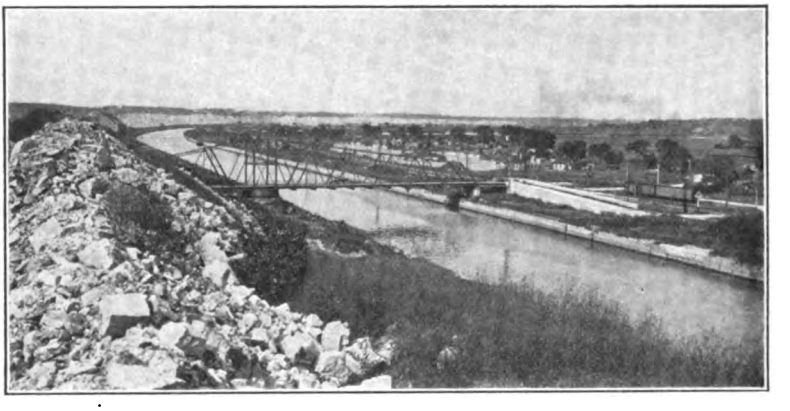


FIG. 6.—Chicago drainage canal; rock section.

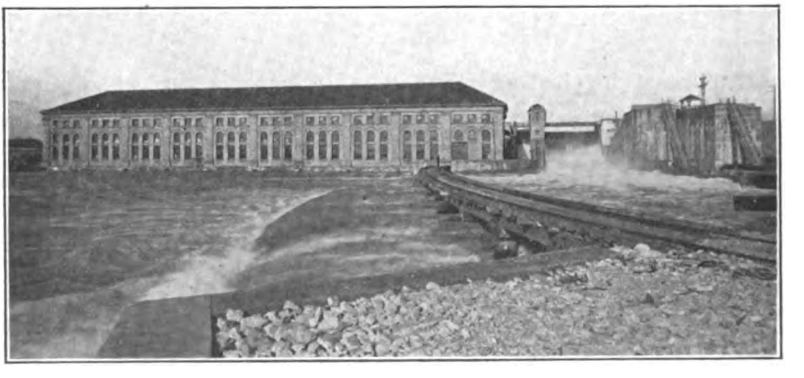


FIG. 7.—Power house at foot of Chicago drainage canal.

Messrs. Rafter and Baker, on page 86 of their book on "Sewage Disposal in the United States," make it plain as their conclusion that while too great a concentration of sewage drives fish away from the vicinity of sewer outfalls, nevertheless where the dilution is adequate the sewage serves as food for fish. In this way they state that there is a practical utilization of sewage by the

dilution method of disposal, whether it is applied to fresh water or to salt water, with a direct return therefrom to the total stock of national wealth.

Nearly 20 years ago these writers recognized in this connection the importance of properly dispersing fresh as distinguished from putrefied sewage. Reference is also made by them to earlier literature on the relation of minute life in water to fish life. It is stated that the most important studies made at that time were by Prof. S. A. Forbes of the Illinois State Laboratory of Natural History and published beginning in 1877 as bulletins of that laboratory. Further data are to be found in earlier reports of the United States Fish Commissioners. Recently Prof. Forbes has published two bulletins on the Illinois river.

Dr. George W. Field, the biologist of the Charles River Dam Committee, reported in 1903 many interesting possibilities as to "balanced aquaria" with respect to pollution of fresh and salt water. Some of his conclusions are summarized by Mr. John R. Freeman in his comprehensive report, from which quotations are given in Chapter X.

In America sanitarians have not given much attention to the part played by the larger forms of life than bacteria in the purification of streams. Matters have been studied in relation to tastes and odors in public water supplies, as is well described by Mr. Whipple in his book on the "Microscopy of Drinking Waters." Yet how the various organisms serve in turn as scavengers and then as food for still larger species has not been closely studied by sanitarians. Engineers who have had wide experience in dock work, such as Mr. Edlow W. Harrison, of Jersey City, have strong views from their own observations as to the important rôle played by organisms visible to the naked eye and directly consuming sewage matters. Compared with the European evidence the scope and significance of these observations is meager.

It has been known for a long time that analytical data do not always indicate in streams, where self-purification has been pronounced, an amount of nitrates corresponding to the degree of purification secured. So many of the data have been associated with streams upon which there are large mill ponds that sedimentation seems to have obscured the important point of recognizing more fully that many sewage matters serve as a direct food for grosser micro-organisms and larger forms of

aquatic life, rather than for the bacteria which might otherwise decompose them.

The literature in this country has been recently much enhanced on this point by an excellent translation by Mr. Emil Kuichling in *Engineering News* of Aug. 31, 1911, of a lecture of the late Prof. Marsson of the Royal Prussian Testing Station. This lecture has recently been revised since Prof. Marsson's death by one of his associates, and in the opinion of the author constitutes one of the clearest expositions of this subject. The entire paper in either German or English should be studied by those who follow closely this general subject, but to outline the viewpoint liberal abstracts from Mr. Kuichling's translation are given as follows:

VEGETABLE PLANKTON: FOOD PRODUCERS

Let us now consider the plants somewhat more closely. In waters the algæ play the most important part, as they exhibit the greatest diversity of form. They are found in all places where water has collected, even in long-stagnant rain water, but their vegetation varies with the seasons and the character of the water. While the plankton contains many unicellular forms and coherent colonies, or strings of such, we find in shallow waters, streams, ditches, and shores mostly the confervæ, or threadlike algæ, which appear as thick mats or strands of light or dark green color. The blue-green group called schizophyceæ is also widely distributed and representatives thereof usually produce the so-called "blooming" of our rivers and lakes, while others, especially the oscillatoria, often settle in strongly polluted water courses, such as the gutters and ditches of unsewered towns and the drainage channels of barnyards. When they form a covering of wet and polluted ground, they usually have a deep black color, but similar kinds are sometimes red, and have been mistaken for dried pools of blood.

The other groups of algæ have only a few representatives in fresh water. Of these the diatoms and bacillariaceæ have been most extensively studied by microscopists, as they are found in all seasons in every water course and pool from the pole to the equator, and as well in icy streams from glaciers as in hot springs. They sometimes appear in such enormous quantities as to render a counting of individuals impracticable. It was formerly believed that in winter our frozen rivers and lakes were devoid of life, as the water was then unusually clear; but on closer examination by filtering the water through a net of fine silk gauze, or by killing the living organisms with alcohol, formalin, etc., and concentrating them by sedimentation or other means, an abundance of microscopic organisms of various kinds, and especially diatoms, will be found in all seasons. The cell body of these algæ is held together by

a silicious skeleton, which has often so delicate a structure as to be defined clearly only by the best microscopes; and hence certain species of diatoms, such as Surirella Gemma and Pleurosigma Angulatum, are used as test objects for the best objectives. Through their brown coloring matter, called diatomin, these silicious algæ are as capable of assimilating organic matter as are the green and blue-green algæ by means of their normal green coloring matter called chlorophyll.

As the assimilative activity of the algæ is a very important factor in maintaining the purity of our streams, it is necessary for us to consider briefly the structure of the microscopic plant cells, of which the higher plants are composed.

In opposition to the animal cell, a well-defined vegetable cell is enclosed by a dense skin, called the membrane. For this reason the cells of a plant are sharply separated from each other. Each such cell possesses a much greater independence than the cells of the body of an animal, or at least of the higher developed animals. In almost every plant cell there is a nucleus, the remainder of the volume being filled by the cell plasm or cytoplasm, which is rich in albuminous substances, and in which the carriers of coloring matter, or the chromatophores, are distributed. These three components (nucleus, cytoplasm and chromatophores) taken together are commonly called protoplasm, or more briefly plasm, which includes all the living constituents or protoplasts of the cell. The chief function of the cell is based upon a reciprocal action between the nucleus and the plasm. The chromatophores or chloroplasts, however, whose predominant green coloring matter is chlorophyll, exercise an important function in the cell, since with the help of the vibrations of light they are enabled to dissociate carbon from the carbonic acid that is contained in air and water, and to prepare with the elements of water organic matter having little oxygen. Polymeric carbonaceous products are thus formed which then develop into starch with certain kinds of sugar; and these compounds, in conjunction with the simplest combination of nitrogen, finally serve to form albumen and other complex combinations for the use of plants, whereby the weight of dry organic matter in the latter is increased. The nitrogen required to form the albuminous compounds is obtained from ammonia and nitrates, and other elements found in the ground and water also appear to play a not less important part in the formation of albumen.

Assimilation.—This entire synthetic process, in which oxygen is dissociated from carbonic acid in the form of gas, is called assimilation. It is the same in land plants as in aquatic plants. In the case of the latter, the highly developed as well as the microscopically small, the necessary supply of carbonic acid is derived only from the surrounding water. In the diatoms the starch is replaced by a fatty oil, which develops more abundantly in the species that grow upon the bottom than in the seamless species which live freely suspended in the water,

and usually constitute the greater part of the plankton of sluggish streams.

After the winter's cold has passed away and the heat rays of the sun are able to penetrate deeply into the water, however, the microscopic plants which have been dormant on the bottom are stimulated to renewed activity and multiply with amazing rapidity, whereupon they are lifted upward by the assimilation of gases and appear on the surface of the water. In March, April and May thick brown masses are seen floating in our rivers, and are commonly regarded as filthy or disgusting matter, but on examining a small portion thereof under a microscope it will be found to consist of amorphous earthy and dead organic matter intermixed with bubbles of gas and swaying tangles of blue-green filaments called Oscillatoria, among which countless diatoms may be seen gliding to and fro. Both of these varieties of algæ possess a remarkable power of motion, which renders it possible for them to crawl about on the bottom or to move in the sludge on the bed.

The seamless diatoms of the plankton do not require this ability to move about, as they are held in suspension by their peculiar shape; but the species that live on the bottom have a seam at which pulsations of plasm that produce motion are manifested. It is very interesting to observe how a parallelism has developed between the biological relations and the morphological structure of an organism. The algæ which are lifted from the bottom by gas bubbles and are not normal constituents of the plankton, are scattered about in running water and purify it by removing therefrom the carbonic acid which has accumulated during the winter. This is done by dissociating the oxygen from the acid and letting the former aerate the water. Such indirectly antiputrefactive organisms generally develop in places where they are most needed, as in localities where the bottom consists of organic sludge or detritus of every kind instead of clean sand.

The production of oxygen, however, is not limited to the activity of the minute plants mentioned, but is maintained by all the other plants which are found in the streams throughout the entire year, even under the ice in winter, although in reduced numbers. As is to be expected, the assimilation gases act very energetically, especially in their nascent state, in oxidizing dissolved organic matter, and atmospheric oxygen is by no means so efficient. The plant life of a stream is therefore of the utmost importance, while the sun must be regarded as the source of the energy required for the development and growth of all these organisms.

Summer and Winter Effects.—Another significant factor must also be mentioned. In the examination of the plankton of small bodies of water, it was noticed that as many organisms of different kinds were found in winter as in summer. The algæ that were held in suspension in the water and constituted the phyto-plankton seemed to thrive as

well during the short daylight of winter as in summer, and thus maintained a similar constancy of the zooplankton. The variation of the temperature, therefore, had no effect, and the only other difference was in the mode of nutrition. It had previously been found that in addition to the matter obtained by assimilation diatoms could absorb albuminous or similar nitrogenous compounds from the medium surrounding them, and hence that they derive their food from two distinct sources. Subsequent physiological experiments showed that diatoms as well as green algæ cannot only absorb carbon compounds from dissolved organic matter, but also organic nitrogen; and that when carbonic acid is rigidly excluded from the water they can digest diluted volatile fatty acids, amido-acids, skatol, urea, peptone, and other substances. Quite recently it was proved that certain diatoms, especially some of the marine varieties, were entirely devoid of chromophyll, or the coloring matter required for assimilation; that they subsisted exclusively on the products of decomposition derived from their surroundings, without recourse to assimilation; and hence that they needed only a medium containing a sufficient supply of food of various kinds. Such algæ have accordingly become true saprophytes, or residents of putrefying matter, and by giving up their chromophyll they have taken the last step from a mixotropic to a heterotropic nourishment.

This direct absorption of dissolved organic matter by algæ is of the utmost importance for the purification of streams by eliminating therefrom the soluble products of putrefaction. As all the algæ that are held in suspension in the water of a river, as well as those that are lodged on the beds and shores, are busily engaged day and night in the work of producing fresh albumen, starch, and indirectly fats, from animal and vegetable refuse matter, it follows naturally that numerous animal organisms will develop in the water to make use of these products and convert them into living flesh.

Through these various investigations and the cyclical transformation of matter it has become possible to understand how a constant biological self-purification takes place in our streams and lakes, even during the winter and under the ice, and that the maintenance of the plant life insures the continuation of the animal life in the water.

Molds or Fungi.—A similar mode of nourishment is exhibited by the molds or fungi. These plants cannot assimilate inorganic matter, like those having chlorophyll, but must rely for their food on the presence of other organisms or of suitably prepared organic matter. They represent the realm of darkness and receive the penalty which Nature has placed on the giving up of independent nutrition; they are either parasites or saprophytes, that is to say, they subsist on the products of the decomposition of dead organisms and vegetable and animal refuse matter, such as is contained in the sewage of cities and the wastes of factories.

Bacteria.—The first of these organisms to appear in the water after the entrance of putrefying matter into a stream, are the bacteria (Schizomycetes). They multiply most rapidly where they find the most food, but they also consume oxygen. The more extensive the bacterial processes the greater will be the consumption of oxygen, and the more unfavorable will become the conditions for the existence of animal life which is dependent on the presence of oxygen in the water. By the removal of the oxygen the respiration of most living organisms is stopped, and they are thus deprived of that source of energy which is essential to the performance of their functions. If the green algæ did not counteract the bacterial consumption of oxygen by constantly producing a new supply of this gas, our rivers would soon become completely poisoned and fouled by the continuous discharge of putrescible matter into them, as is now done by our large communities. The fact is, however, that a large proportion of the microbes in the sewage of our cities die naturally soon after reaching the rivers.

The bacteria must not be regarded as enemies exclusively, as they are a necessary factor in all processes of decomposition that take place, not only in water, but also in the whole economy of nature. Their most important function is to liquefy the organic components of dead vegetable and animal matter, and render them capable of being absorbed by living plants. They decompose proteids, or albuminous substances, by abstracting thereform ammonia, which is then oxidized to nitrous and nitric acid by certain nitrifying organisms. In this manner the decomposed organic raw material begins anew its course in the circulation of matter. For the formation of new food the soluble compounds of nitrogen, such as salts of ammonia, nitrites and nitrates, are of primary importance, and next come phosphates, silicates and other salts.

The magnitude, and eventually the cessation, of this new production of food is governed by Liebig's law of the minimum, according to which the energy of vegetation is limited by the energy of the least quantity of indispensable food material that is present. As soon as this is used up further life comes to a standstill.

In the action of bacteria upon the dissolved nitrogenous matter that reaches the streams a difference occurs in different seasons. The decomposition of putrescible material proceeds much more actively and quickly in the warm season, while in winter the phytoplankton and the filamentous fungi of the water consume a large proportion of this material by their peculiar mode of nutrition; but at higher temperatures the nitrites and nitrates resulting from the mineralizing processes that take place in the water are decomposed by the separation of free nitrogen thereform. This decomposition is effected by denitrifying bacteria, which often require a relatively high maximum of temperature. By their activity in the warm season, when the processes of decomposition

are most energetic, the poisoning of the water by inorganic compounds of nitrogen is prevented. The free nitrogen, however, cannot be utilized in appreciable degree for the structure of aquatic plants, and it is accordingly lost in the circulation of matter in water.

The orderly relations between the conditions of production and the actual production are determined to a large extent by the despised bacteria. Brandt has formulated some important considerations in this direction in his study of the circulation of matter in the sea; and it appears therefrom that the disturbing activity of the denitrifying bacteria is associated with the remarkable fact that the magnitude of production in the oceans of the arctic and temperate zones is not inferior to that of the tropical seas. This is directly contrary to the activity of land organisms, which exhibits a large decrease in production in proceeding from the tropics toward the poles. In the warm seas a relatively smaller production can take place, in spite of much more favorable conditions, in consequence of the greater decomposition of an indispensable substance of plant food, corresponding to the law of the minimum, while in the cold water a greater quantity of nitrogenous compounds is available to the marine producers, owing to the retardation or suppression of this decomposition.

It is not our purpose to consider here various other bacteriological details, such as the vitality of pathogenic germs in river waters.

A series of other fungi adapted to aquatic life also play an important part in the purification of streams. Foremost among these may be mentioned the filamentary bacteria, of which Sphærotilus Natans is the most widely distributed species. This fungus is found in all places where extensive processes of putrefaction take place in water, and especially at the points where liquid wastes containing much nitrogenous organic matter are discharged. Such liquids are chiefly the sewage of cities and the wastes from sugar, starch, glue and cellulose factories, breweries, distilleries, etc. The stronger the pollution the greater will be the development of sphærotilus, which will be rendered visible by thick whitish flocculent growths on submerged leaves. Under certain conditions Leptomitus Lacteus will also appear, although this aquatic fungus is much more highly organized. Under different conditions other varieties will develop, but none of these deserve as much consideration as the sulphur fungi, which constitute another large group.

Beggiatoa.—Among these the Beggiatoa are of most significance for a river, as my observations have shown that the other sulphur bacteria, and especially the red ones, are found more generally in stagnant water. The beggiatoa, of which a number of species are known in southern waters, can exist only in flowing water; that is to say, where a supply of oxygen is available. Individual filaments of this fungus can always be found in examining microscopically samples of any river mud or sludge, but its rapid growth takes place only when sulphureted

hydrogen is present as a product of the putrefaction of albuminous substances derived from either vegetable or animal matter. The beggiatoa separate the sulphur from sulphureted hydrogen and store it in their cells. Sulphur is an important source of energy for these plants, and serves the same purpose as carbon for the other organisms in the process of breathing or transpiration. It is, however, not assimilated but becomes oxidized into sulphuric acid by the oxygen present in the water, and this acid then combines with the lime that is in solution in the water to form gypsum. These sulphur fungi thus have the highly important function of removing from the water the sulphureted hydrogen that is so dangerous to animal life, and is so offensive esthetically.

Pollution Indexes.—When found in large quantity in a stream, the various fungi mentioned above afford reliable evidence that the water has been polluted in higher degree than is usual under natural conditions, and they accordingly serve as guides to the source of the contamination. All of them have a great purifying power, but where large quantities of marsh gases rise from putrefying mud they become entirely powerless, as the bacteria of putrefaction are then exclusively at work. The discovery of guiding forms of fungi has become of great importance in arriving at a correct judgment of the quality of a water, as they furnish us with much more characteristic and quicker results than the chemical analysis of samples of water taken arbitrarily.

We must also bear in mind another physiological process by which plants manifest further similarities in metabolism or change of matter to that of animals. A plant builds up its substance in the same manner as an animal, by forming directly usable food material, especially albumen, from the carbohydrates (sugar and starch) acquired as previously described and from nitrogenous compounds, for the maintenance of the molecules of living protoplasm; and it is also capable of respiring or breathing like an animal, in the daytime as well as at night, when the activity of assimilation has declined. In this process of breathing or transpiration, which is, however, not localized as in many animals, a plant also gives off carbonic acid and absorbs oxygen, like an animal. The same is likewise true of the bacteria, in addition to their fermentative activity.

If the materials which are produced in the green cells of a plant from inorganic food remained therein unaltered, they would represent an accumulated dead capital. By the breathing process, however, the heat which is made latent in assimilation becomes liberated by the decompostion of a portion of the carbohydrates. When there is a deficiency of oxygen in the water, as happens from the discharge therein of putrescent liquid wastes, the aquatic plants are deprived of the possibility of breathing and must perish; this fate befalls the higher classes

of aquatic vegetation as well as the lower ones, like the algæ, and especially the phyto-plankton.

The breathing or transpiration of plants is also accompanied by certain disadvantages in the case of stagnant bodies of water, in which the oxygen consumed by the animal life is not restored during the night. Thus it was observed that in trout ponds which contained an excess of filamentous green algæ, numerous fish died about daybreak, having been suffocated from lack of oxygen. The more intense the growth of such aquatic plants during the daytime, the more energetically will their breathing process proceed; and this may readily exhaust during the night the greater part of the oxygen contained in a confined body of water, especially in the warm season. This breathing is really a combustion of carbon compounds; and as such combustion is facilitated by an increase of temperature, it follows that up to a certain limit the transpiration of the algæ will be the more copious in proportion as the temperature of the materials and their surroundings increases. A reasonable explanation is thus at hand for so unusual a phenomenon as the death of healthy fish in pure water.

ANIMAL PLANKTON: FOOD CONSUMERS

Bacteria Eaters.—Let us next take up the consideration of the most important groups of animals which help to purify polluted water. Among the protoza, which in comparison with the metazoa have the morphological value of a single cell, the colorless Flagellated Infusoria may be cited first as food consumers. By means of their small lashes, they direct minute particles of food, bacteria, etc., into their mouth-vacuoles which retain them. The numerous species of monads are thus typical bacteria-eaters, and in stagnant, putrefying water they often develop in extraordinary numbers. There are also many kinds of Ciliated Infusoria that eat bacteria. They are somewhat more highly organized than the preceding class, and usually they have a mouth-aperture with a passage-way to the interior. With their cilia or their undulating membranes they produce whirling currents in the surrounding water containing bacteria and other minute particles of food, including the flagellates just mentioned, whereby such bodies are brought into their vacuoles. These relatively large unicellular organisms thus dominate over the other living organisms in their vicinity, according to their size, like a cannibal among fish. Many of the Metazoa, including the Rotatoria, are likewise bacteria-eaters, and obtain their food in the same manner as the ciliates. Besides bacteria, this food material embraces other bacteria-eaters, diatoms, small algæ, etc. If many bacteria-eaters are found in a water, it can safely be inferred that many bacteria are present, and hence also a quantity of putrefying substances, thus rendering a tedious counting of germs wholly unnecessary before expressing an opinion as to the sanitary quality of the water.

A great horde of lower animals is therefore striving incessantly to destroy the bacteria. If the latter disappear, the bacteria-eaters will also vanish, as they cannot find adequate subsistence in the purer water, and must either starve or become the prey of other animals. Heretofore it was believed that the bacteria died gradually and were subject to a process of sedimentation, but if such were the fact the beds of our streams would present a very different appearance. It is also highly improbable that an actual settlement of such extremely small organisms can take place in a stream having even a moderate current. Obviously some of the bacteria will be dragged to the bottom along with the heavy matter in suspension, but the great majority will not settle. Experiments in this direction have been made for improving the condition of the water in large aquaria and fish ponds by the precipitation of clay; but few have thought of the natural biological process of water purification, because an unexpectedly extensive view of these processes has been gained only quite recently by planktological and thorough hydrobiological investigations.

Other Food Consumers.—Among the organisms that are carried in suspension in water the minute crustacea must also be considered. They are found in all seasons in the plankton of rivers, although in less quantity in swiftly-flowing streams. At one time the Cladocera, or water fleas, will predominate, while at another time the Copepoda will be the more numerous, according to their cycle of propagation. Their significance for the purification of water has likewise not been sufficiently appreciated. Concerning the quality of their food, numerous but not conclusive observations have been made. Some investigators assert that they live only on animal food, such as protozoa, while others claim that they use only vegetable food, such as diatoms and other minute algæ; but it must be remembered that both protozoa and minute algæ usually adhere to decaying detritus of animal and vegetable origin.

An enormous multiplication of Daphnia has been observed in highly-polluted village ponds, in which, however, various oxygen-producing algæ, and especially the euglena previously mentioned, rendered respiration or breathing possible. The question is, what becomes of the great quantities of offal and excreta, the many remnants of decaying plants, the refuse of communities, and the finely-divided factory wastes of every description, which find their way into our streams, even under normal conditions, if a large portion thereof is not consumed by the aquatic detritus-eaters and the omnivorous fauna before settling to the bottom. By increasing the discharge of sewage into a river, a very large increase in the number of water-fleas has resulted, as was observed at Hamburg and elsewhere; and because the substantial value of the crustacea is materially greater than that of the rotatoria, the production of living animal substance is greater at all times in the sewage-polluted portion of the river than in the clean-water portion. Most of the larger

crustacea are omnivorous, and many of them do not spare even their own progeny.

Food for Fish.—In addition to the bacteria-eating and omnivorous animals cited there are many other species, especially rotatoria and large ciliata, which feed preferably on algæ, as their digestive cavities are frequently found stuffed with green algæ and brown diatoms. All of these minute animals, and particularly the small crustacea, are of importance as food for fishes, and chiefly for young fish. After consuming the contents of their egg sacks, the latter take for their first food the very small animalcules, such as rotatoria and young crustacea; as their size increases, they feed on full-grown crustacea, and so on until they finally become the prey of larger fishes. The plankton thus forms the beginning of the cyclical course of matter for a fish. Carp can feed exclusively on plankton crustacea until they attain a weight of 1 pound. The putrescent matter that finds its way into our waters is thus transformed into useful fish-flesh; and from the relations of the interchange of matter between plant and animal it becomes evident that a certain degree of pollution of a stream is necessary from the point of view of social economy.

ANIMAL LIFE ON STREAM BOTTOMS

Balancing Wastes and Assimilators and Consumers.—Although the foregoing considerations have shown that our rivers and their inhabitants can readily master the natural pollutions, such as the domestic sewage of our cities and certain trade wastes, and that in many cases clean water is again found flowing in streams only a comparatively short distance below the point of contamination, nevertheless it is necessary to bear in mind that the quantity of putrescible and putrefying matter must always be in proper proportion to the volume of water. My observations have established the fact that the sewage of small cities and the drainage waters of sewage farms of moderate size are easily digested by relatively small streams; while, on the other hand, the insufficiently-purified liquid wastes of large isolated factories, which are usually produced in excessive quantity at a certain time in the year, as after harvest, have often caused serious damage through distances of many kilometers in relatively large streams. In such cases a severe loss results to the fisheries.

Trade-waste Dangers.—Concerning the capacity of a stream to digest or purify sewage and other wastes, definite figures and limits, such as those given by Pettenkofer, cannot be made readily. The maximum quantity of such liquid that a stream can digest depends not only on its physical characteristics, but also on its individuality in other respects. Both the biological and the chemical factors must here be taken into consideration. If the industrial wastes contain much acid, alkali or other matter that is poisonous to the animal and plant life of a stream.

entirely different conditions are presented from those which occur with domestic sewage and harmless wastes. Thus it has been found that tar products have destroyed all the animal and plant life in the mud bottom of long stretches of river, and that alkalies and acids have killed off every kind of fish by attacking the gills and thereby causing death by suffocation. With a proper quantity of harmless organic wastes, on the other hand, the microscopic organisms suspended in the water, as well as the larger flora and fauna, will labor incessantly to keep the stream in a healthy condition.

In regard to injury to fishes, the opinion has hitherto been that the numerous kinds of industrial wastes consisting of finely divided insoluble matter, such as is produced by cellulose, paper, cloth, cotton and rag mills, and also by mines and iron works, are all injurious by their tendency to lodge in the gills. Such waste matter may be either flocculent, or in the form of fine hairs or fibers, or sharp-edged hard grains. My own observations indicate in general that such is not quite the case. A healthy fish has the power to eject all such foreign bodies from its gills. If, however, the gills are irritated by only small quantities of acid, alkali, or even salts, these organs endeavor to protect themselves against the action of such chemicals by exuding a considerable quantity of mucus upon their surface; and the damage is then done by the adhesion of the particles of cellulose, textile fiber, or other matter to this mucus and the accumulation of such matter thereon, until the gills become so completely covered as to cause suffocation. A copious secretion of mucus by the gills is induced by very small amounts of such chemicals in the water. When the chemicals are present in large quantity or strongly concentrated, the gills are destroyed directly by disintegration.

If acids are discharged into a stream, a new factor for the self-purification of the water is introduced by the neutralizing capacity of the dissolved bases. Thus the bicarbonate of lime usually carried in solution in the water will neutralize a certain quantity of the acids; and in the case of sulphuric acid a combination with lime will occur, whereby the resulting insoluble sulphate of lime, or gypsum, will settle on the bottom. Such a self-purifying process, however, is not a natural one, as the acid of the sulphate in the mud is sometimes reduced by other processes to sulphureted hydrogen. This latter is a well-known poison for fish, but it may be rendered harmless by the operations of the sulphur bacteria, such as the Beggiatoa previously mentioned.

Similarly, if caustic lime is thrown into the stream, it will ultimately be rendered harmless to fish by combining with the free carbonic acid in the water and forming either insoluble carbonate or soluble bicarbonate of lime, the latter being a normal component of many natural waters. This process, however, is not very rapid, and before its completion the water must generally flow through long distances.

OTHER FACTORS AND GENERAL CONCLUSION

A consideration of all the remaining factors that enter into the self-purification of a stream would require much more time than is now available, and hence only the more important ones can here be indicated. They are mainly of a physical character, such as the current and the aeration of the water induced thereby; the intensity of the sunlight, and even also that of the moonlight; the more or less rapid sedimentation of the suspended mineral matter in the water; the dilution caused by rain, the inflow of ground water, and by the various tributaries; the quality of such additions; the influences of temperature, climate and seasons, etc.

The self-purification of a stream thus involves a large number of factors, all of which stand in mutual relationship and interaction like the wheels of a clock, and the main object of the foregoing considerations is to point out the great importance of the action of animal and plant life alone in conserving the purity of our waters.

RÉSUMÉ

The disposal of sewage by dilution in inland streams is the most prevalent method of sewage disposal in America. In some cases no nuisance results and it is a proper method. In other cases the results are unsatisfactory because of unsightly conditions upon the surface of the stream, offensive odors from the decomposition of the flowing mixture of sewage and water or of sewage sludge, the suffocation of fish due to excessive reduction of the dissolved oxygen in the water, and the infection of the water with disease germs of sewage origin, thus rendering it dangerous in a raw condition for drinking or bathing purposes. One or all of these complications may arise and their significance varies widely with local conditions.

Normally it is impracticable to purify sewage and to expect that river waters in a raw condition will be safe for drinking purposes. It is much better to purify the public water supply. In some instances the river waters are so polluted that the entering sewage should also be treated or purified. Sterilization or disinfection of sewage is available in serving this purpose without going to the expense of complete sewage purification, in cases where disease germs alone require attention in connection with safe drinking water supplies.

A dilution of 4 to 7 cubic feet per second is ordinarily required for the sewage of each 1000 of population connected with the sewers, in order to prevent objectionable conditions. A more precise degree cannot now be stated, owing to the influence of trade wastes, the initial oxygen content of the diluting water, the

time in which the bacteria may act upon the organic matter, the addition of further oxygen obtained from fresh diluting water, increased quantities of sewage from cities lower down the valley, the effect of sewage mud and the requirements for the protection of fish life.

There is a conflict in opinion as to the residual atmospheric oxygen which should be allowed to remain in a sewage polluted water. The range within permissible limits varies with the views of different workers from 20 to 70 per cent. of that necessary to saturate the water. Major fish life should be provided with at least 2.5 parts per million, which is about 30 per cent. of the oxygen needed for saturation in ordinary summer temperatures. Some species of fish may need more than this. It is more important to keep a high degree of purity in the upper reaches of a stream where fish spawn than it is in the lower reaches. Various forms of aquatic life need attention in this connection. Some consume sewage matters directly and are of value as food for fish. Others die, decompose and consume oxygen. Still others produce oxygen.

So long as some oxygen surrounds all sewage matters anaerobic decomposition with its foul odors is not a factor of importance. Sewage mud or decomposing solids in shallow water may give trouble, however, under some circumstances where the accumulations are deep and extensive.

Engineering literature shows that sludge deposits near sewer outlets and inadequate mixing of the sewage with the diluting water are serious faults of the dilution method which need prompt correction in a great many cases.

Although marginal pollution is frequently the chief shortcoming of the dilution method as now practised, yet its correction would not allow satisfactory results to be obtained in some cases. Undoubtedly there is a well-defined effort on foot looking to the removal of solid sewage filth from many rivers. As the factor of safety against undue pollution becomes less the tendency is for a river to approach the condition of an "open sewer" at an increasingly rapid rate in comparison with the added quantities of sewage pollution. Caution is necessary.

Fortunately this cleaning of rivers can now be done to a considerable extent by screens or settling tanks without the expense of filtration. Care should be taken, however, that the cost of treatment works does not exceed the benefit to be secured therefrom, when considered in connection with other sanitary needs of a community. A keen sense of proportion is needed.

CHAPTER IX

DILUTION IN LARGE LAKES

The disposal of sewage by dilution in large lakes, particularly in the Great Lakes, offers a number of points of similarity to the dilution method as applied to inland streams; but it also shows several distinct differences.

SIMILARITY TO RIVERS

The points wherein disposal of sewage by dilution in large lakes resembles disposal in inland streams may be briefly summarized as follows:

1. **Floating Solids.**—Before dispersion in lakes sewage should be freed substantially of floating solids and objectionable grease, in order to guard against an unsatisfactory appearance of the lake surface and also of beaches which otherwise might be made offensive by stranded solids.

2. **Settling Solids.**—Sewage should be freed from those suspended matters which under local conditions would produce offensive sewage mud or sludge banks. When discharged in deep water there is less likelihood of difficulty in this regard than in shallow rivers. In some cases it may be preferable to allow the deposits to accumulate and then to dredge them from time to time. This is a question for local determination.

3. **Efficient Mixing.**—This is just as necessary as in the case of rivers, and its neglect explains many difficulties in present works.

4. **Bacterial Decomposition.**—This is substantially the same proposition that has to be reckoned with in the case of rivers. In brief, decomposition should proceed on an aerobic basis only.

5. **Oxygen Balance.**—This is a corollary of the preceding point, and due consideration should be given to reasonable factors of safety, taking into account the effect of time, temperature and the oxygen content of the lake water used for dilution.

6. **Fish Protection.**—Fish life should be protected against suffocation by striving at all times for a reasonable residual of dissolved oxygen.

7. **Aquatic Life.**—The consumption of sewage matters by various forms of animal and vegetable life that grow in lake waters should be taken into account. It brings up the question of the physiology of lakes, which is detailed in this chapter at some length, but to which little consideration has been given hitherto with respect to sewage disposal.

8. **Disease Germs.**—The question of the dying out of disease germs in the diluting water and of their deposition at the bottom thereof shows substantially no new features for lakes as against river problems.

DISSIMILARITY TO RIVERS

These may be briefly outlined as follows:

1. **Translation Currents.**—The currents in lakes due to the movement toward the outlet is so small that ordinarily it may be practically ignored. Millponds sometimes show an absence of well-defined velocities, but broadly speaking it is a distinctly new factor to be reckoned with in the use of lakes for the disposal of sewage.

2. **Wind Currents.**—The action of winds, with their varying velocities, produces a pronounced but variable result as to the available currents for the dispersion of sewage. On the other hand, they promote a mixing of the oxygenated surface waters with the lower layers, in which the water is at times less charged with oxygen. Wind velocities vary tremendously with the condition of the weather, the size of the lake and other factors.

3. **Irregularity of Currents.**—Wind velocities cause numerous deflections and irregularities in currents. Frequently top and bottom currents are in opposite directions. A wind blowing from shore on to the lake naturally drives the surface water away from the shore, but the undertow or bottom current is toward the shore. A reversal of currents results even more strikingly when the wind comes from the lake to the shore. Depending somewhat upon the contour of the shore line, numerous intermediate and complex resultants are naturally produced when wind directions are not normal to the shore line. These factors doubtless explain some surprising results, although information upon them is meager owing to the danger attending the study of the conditions when high wind velocities prevail on the Great Lakes.

4. **Irregularities in Sedimentation.**—Wind velocities, as above mentioned, naturally produce widely different results in point of the distance to which they carry settling solids of sewage origin. More than that, they produce a bottom scour, and thus may transport at times of storm sewage sediment, including bacteria, which may have been deposited some little time previously during fairly calm weather. In the Great Lakes wind action will produce bottom disturbances at a depth of 30 to 40 feet and perhaps more.

5. **Thermal Stratification.**—When undisturbed by wind action a difference of about 2.5° Fahrenheit in the temperature of the water is sufficient to cause a variation in density that results in the stratification of water. This varies much with different lakes with respect to the latitude in which they are situated, their area and depth, and requires study in each case. Naturally the supply of oxygen is practically excluded from the denser bottom waters, and here is formed a zone of decomposition in which anaerobic bacteriolysis occurs of organic matters of strictly vegetable as well as of sewage origin. The top waters are the zone in which thrive many grosser forms, particularly the chlorophyl-bearing organisms. In the bottom layers are found complications even in unpolluted lakes with respect to the death of fish from suffocation. Sometimes this happens in unpolluted shallow lakes, owing to the decomposition of large amounts of organic matters of strictly vegetable origin.

6. **Greater Clearness.**—Lack of turbidity, such as found in many of our large rivers, characterizes the water of most lakes, particularly the Great Lakes. Wind action sometimes stirs up the bottom deposits near the shore, so that for short periods this is not always true. Speaking generally, chlorophyl-bearing organisms find a more favorable environment in lakes than in many rivers.

We shall not attempt to dwell in great detail upon these points of difference, as they bring forth no well-defined new principles not explained in the preceding chapter. It is simply a question of giving due consideration to a number of factors which behave differently in large lakes than in rivers.

We shall cite some recent studies of the lakes of Wisconsin as illustrative of a number of scientific phenomena which are highly instructive to those who have to do with sewage disposal, although the subject of sewage disposal by itself is not touched upon in the

studies mentioned. This investigation, with a recital of experiences at numerous cities along the Great Lakes, will sufficiently exploit the principles involved in and the present status of the field of sewage disposal for lake conditions.

THE PHYSICS, CHEMISTRY AND BIOLOGY OF LAKES

Recently there has been published as Bulletin 22 of the Wisconsin Geological and Natural History Survey, 1911, an excellent report on the Inland Lakes of that State with especial reference to the Dissolved Gases. The book is the result of some ten years' investigations by Messrs. Birge and Juday. While serving as a contribution to science, it puts so many physical, chemical and biological points in a clearer manner than hitherto that we have abstracted the substance of the report in the following pages. The first third of this abstract is reproduced nearly in full, but the remainder, with respect to the different gases and their relation to physical and biological conditions is condensed to the main features developed. We have added a number of side headings to call attention to particular topics.

BIRGE AND JUDAY'S INVESTIGATIONS OF WISCONSIN LAKES

The following report deals with the dissolved gases of the inland lakes of Wisconsin. It reports the distribution of these gases in numerous lakes and the cause of variations in distribution due to depth and season. In this introduction we purpose to sketch briefly the principles which are more fully stated and illustrated in the succeeding pages.

The lakes studied are not large, as the area does not exceed 40 square kilometers (15 square miles); nor are they very deep, since the maximum depth is 73 meters (237 feet). They are glacial lakes, usually placed in drift basins; with low banks and are either fed from the ground water or have relatively small affluents. They are covered with ice during several months of the winter and the surface temperature ordinarily reaches a maximum of 27° to 37° Centigrade during the summer.

Thermal Stratification.—The cycle of the season induces a corresponding cycle of physico-chemical changes in the water of these lakes, chiefly conditioned by temperature. The lake starts in spring with a uniform temperature below 4°, when complete circulation of the water is possible. The advance of summer quickly checks circulation by warming the surface water, and soon produces a permanent thermal

stratification. This leads on to the formation of an epilimnion,[1] sharply separated from the cooler water by the thermocline. This situation may be developed in small lakes as early as the opening of May; in larger lakes it may not be completed before the first of July. The epilimnion thus formed varies in thickness, in midsummer, from 3 meters in small lakes to 10 meters to 12 meters in large ones. After the epilimnion is established circulation is confined to this stratum of the lake and is very imperfect even there so long as the lake is gaining heat. As autumn comes on the lake cools, the epilimnion increases in thickness; finally the lake "turns over" and becomes homothermous; and the fall period of full circulation begins. This happens at a time which varies from late September to December, according to the area and depth of the lake. It lasts until the lake is frozen, which may occur in late November or early January, varying with lake and season. Circulation then ceases until spring.

Thus during the greater part of the year, free circulation of water and consequent exchange of gases with the air are much restricted or wholly cut off. The lake is saturated with gases from the atmosphere in the fall and in early spring. As soon as direct thermal stratification appears, the lower water begins to be excluded from the circulation and consequently from contact with the air. This exclusion may be interrupted by violent winds which temporarily restore circulation. But it soon becomes permanent; and the stratum of circulating water becomes increasingly thinner until the thermocline appears and the permanent summer conditions are established. Thenceforward until the overturn only the water of the epilimnion can have direct contact with the air and only indirect exchanges are possible for the gases of the lower water. Practically, the lower water is cut off from the air.

Influence of Aquatic Life.—Superimposed on this annual cycle, determined by the march of the seasons, is another series of physico-chemical changes due to the plankton inhabitants of the lake. These consume certain substances dissolved in the water, manufacture others; add some materials to the water and subtract others. This is done in the most complex fashion, varying with the kind of plankton and with many varying conditions in its life and environment.

It is convenient to group these activities, so far as they relate to gases, under two heads; those which liberate oxygen and those which consume it. A correlative classification would be into those processes that consume carbon dioxide and those which liberate it. The first class includes the photosynthetic activities of plants; the second comprises the respiratory processes and those of decomposition.

[1] By *epilimnion* is meant the upper stratum of water found in summer above the thermocline and whose temperature is nearly uniform. The region below the thermocline may be called the *hypolimnion*. See Birge, On the evidence for temperature seiches; Trans. Wis. Acad. Sciences, Vol. XVI. pt. 2, page 1006, 1909.

Oxygen Producers.—Photosynthesis consumes carbon dioxide and liberates a corresponding amount of oxygen. It demands a certain quantity of energy in the form of light. It is therefore most vigorous near the surface, and is limited to a stratum of the lake whose thickness varies with the color and turbidity of the water. In highly colored or turbid lakes the *zone of photothesis* may be only two meters to three meters thick; in clear lakes it may extend to the depth of 10 meters or even farther. The oxygen contents of this zone vary with the ratio of the liberated oxygen and that absorbed from the air to that consumed by respiration and decomposition. In the water below, the amount of oxygen will depend on the rate of consumption as compared with the rate of supply by diffusion from the upper stratum, or by circulation due to temperature changes or to wind.

In the zone of photosynthesis the oxygen may be present in sufficient quantity to saturate the water. It may rise above this amount, especially if circulation of the water is hindered by calms; if photosynthesis is slow the oxygen content may sink below saturation. In an opaque lake the zone may not extend to the thermocline; and in periods of deficient circulation the oxygen content of the lower part of epilimnion may become low. In clear lakes, especially if they are small, the zone may extend below the epilimnion and so below circulation; and in these cases a large excess of oxygen may accumulate at the region of the thermocline.

Sources of Carbon Dioxide.—In the processes of photosynthesis the carbon dioxide in the water is consumed. Its sources are four: from the air, from ground water, from the decomposition of organic matter and from respiration, and from dissolved bicarbonates of calcium and magnesium. The air seems to afford only a small supply; and the same may be said of the ground water under ordinary conditions, although this source may be important in small, spring-fed lakes.

Oxygen Consumers.—The process of respiration consumes oxygen and sets free carbon dioxide at all depths where animal and plant life occur. Its effects on the dissolved gases can hardly be separated from those of decomposition. This process, too, goes on at all depths, consuming oxygen and liberating carbon dioxide. But as both animals and plants sink after death, most of the decomposition goes on in the deeper water, and especially close to and at the bottom. There is ordinarily an accumulation of free carbon dioxide in the lower water increasing with the depth, and a corresponding reduction or exhaustion of oxygen. After the oxygen is used up anaerobic decomposition continues, with evolution of carbon dioxide, methane, and carbon monoxide. The lower water of a lake forms a *zone of decomposition*, whose processes are most vigorous at the bottom and decrease in intensity upward. It should be observed that this term is applied to the region where decomposition is the predominant process and where most, though by no means all,

of the decay occurs; while the zone of photosynthesis includes the stratum where all the photosynthesis occurs.

Distribution of Gases.—Thus the vertical distribution of gases in a lake is indicative of fundamental biological facts. The quantity of life which the limnetic region of a lake can support is in general a function of the amount of green plants which it can produce. This in turn is limited largely by the quantity of carbon dioxide available for photosynthesis. If a lake is so shallow that the whole of the water is circulated, the zones of photosynthesis and decomposition overlap and the carbon dioxide can readily be used over and over again with correspondingly vigorous growth of plants. If, however, an epilimnion is formed, none of the carbon dioxide liberated below it can be used in the upper water until circulation extends downward. Thus much of the carbon dioxide may be locked up in the lower water until late in the fall, when the period of growth has passed. In lakes containing much plankton a large share of it may be decomposed under anaerobic conditions, yielding in part methane and peaty products which are not available for further use in the lake.

The zone of photosynthesis is, under ordinary conditions, subject to a continual loss of part of its stock of carbon dioxide by the sinking of dead and dying planktons. This is only very partially replaced from the air or other sources. Since this is the case, the form of the lake-basin is of importance in the economy of the lake. A lake with shoal margins, offering a chance for much decomposition above the thermocline, will produce—other things being equal—more plankton than a lake of similar area, but with steep slopes and deep water. In the latter case, almost all matter manufactured near the surface is decomposed in deep water below the region of circulation; and therefore is more or less permanently withdrawn from the possibility of being used again.

Under these conditions, the carbon dioxide available for plants in the dissolved bicarbonates becomes a valuable supply. Lakes containing a large amount of these substances possess a source of carbon dioxide lacking in soft-water lakes, and can therefore support a larger population of plankton. The reduction of the bicarbonates to monocarbonates gives an alkaline reaction to the upper stratum of the lake. These monocarbonates must take up the carbon dioxide liberated in the upper water by respiration and decomposition, and more will be absorbed from the air than is possible if free carbon dioxide is already contained in the water. Thus the presence of an abundance of dissolved carbonates increases the supply of carbon dioxide for plant use, both directly and indirectly; directly, by the original stock of half-bound carbon dioxide in the bicarbonates; indirectly, because the monocarbonates take up more carbon dioxide from the air than would be absorbed without their aid, and also absorb that liberated in the upper

water by respiration and decay. Much of this last would escape into the air, especially at night, if not so absorbed.

In such lakes the epilimnion is permanently alkaline during the summer, which shows that more carbon dioxide is withdrawn from the bicarbonates than is supplied to them from other sources, and more than is made good at night. The process goes so far that monocarbonates, especially calcium carbonate, are precipitated, to be redissolved by the free carbon dioxide in the lower water or to accumulate in the mud at the bottom.

Animal and Plant Life.—The inhabitants of an inland lake form a closed community in a stricter sense, perhaps, than the term can be applied to any other non-parasitic assemblage. The number of species living under these conditions is small and closely similar in different lakes. Only small additions are made to the food supply from without and these come slowly. The lake is dependent on its own stock of green plants for the stock of organic matter available for food of other organisms; and the possible amount of green plants is limited by the raw material supplied for photosynthesis from the lake itself. The critical factor then, in the economy of a lake with small in- and outflow of water is the provision for the vertical circulation of the water in the lake. But this circulation is very imperfectly effected at best, and is often wholly absent for most of the water.

The animal plankton has not shown any close correlation with the dissolved gases considered either with reference to kind or quantity. These gases seem to have no chemotactic effect on the zooplankton, nor do the gaseous products of decomposition, as they exist in lakes, appear to have any unfavorable effect on the animals, such as might determine their distribution in the water of the lake. The zooplankton is excluded from water whose supply of oxygen is too small; but sensitiveness to deficient oxygen does not appear until the supply of the gas is much reduced. These animals do not begin to withdraw from water until the oxygen supply is reduced to 0.2 or 0.3 cubic centimeter per liter—a very small percentage of the normal amount. Few animals remain in water which has less than 0.1 cubic centimeter. Thus the whole phenomenon of response to declining oxygen takes place within very narrow limits in the quantity of the gas. It has been possible, therefore, to give only broad and general conclusions in this matter, and we have not been able to work out exact correlations for the various species or other groups.

It may not be out of place to state briefly our view of the results of this investigation, and also of some of the unsolved questions on which it touches. It is a study in the statistics of lakes and from that point of view must be judged by the quantity of observed facts which underlie it and by the way in which the facts are handled. But the facts also represent the effect of processes which go on within the lake, and the

report should show the relations between the changes in dissolved gases and these other processes.

We believe that judged from the first point of view this report gives a reasonably full account of the dissolved gases in the waters of Wisconsin lakes. It sets forth in sufficient detail the facts of the kinds, the amount, and the variation of these gases; of their vertical distribution; of the effect of the seasons and the plankton on quantity and distribution; we have been able to distinguish the different types of lakes which result from these facts.

Lake Physiology.—But even though we may feel that this investigation is reasonably adequate from the statistical point of view, we are sure that no reader of the paper is more keenly conscious than ourselves of its essentially fragmentary character, when judged on another and much more important side. This study is fundamentally concerned with one aspect of the physiology of a lake, and therefore with a yet almost wholly undeveloped science. Perhaps the chief interest which our work has had for us has been the fact that its progress has revealed to us the existence of physiological processes in lakes as complex, as distinct, and as varied as those of one of the higher animals. The processes which we have studied are intricately bound up with physical, chemical, and biological processes of every kind, of which limnologists are still in large measure ignorant. If the story of the dissolved gases is to be adequately told, there is needed a quantitative knowledge of the chemical results of the vital processes of the plankton plants and animals; a knowledge of which we possess hardly a beginning. We need a similar knowledge of the processes of bacterial decomposition in lakes, whose accurate study still belongs to the future. In spite of this ignorance, we have not hesitated to put forward our conjectures regarding the meaning of various changes in the gases and their relation to other processes; fully expecting that many of these conjectures will prove erroneous, and sure that future knowledge will render all of them inadequate. But we know of no better way to direct attention to problems which need study than to indicate the probable, or possible, connection of the changes which we have found in the dissolved gases with other processes of lake physiology.

OXYGEN

It has already been noted that the 156 lakes that have been studied cover a wide range of conditions. There are marked differences in the size and depth of the various lakes, in their exposure to the action of the wind, in the amount of the decomposable material found in the water, and also in climatic conditions. In addition to these general differences, it may be said that almost every lake possesses some

individual characteristics which affect more or less markedly the gases dissolved in the water, more especially the oxygen. In view of this diversity of conditions, then, it is not surprising that the quantity of oxygen dissolved in the waters of the various lakes and its distribution therein, should show marked differences, because this oxygen is subject to the influence of so many factors. Not only do the different lakes show important differences in oxygen conditions, but there may be annual variations in the same lake. These are due, in a large measure perhaps, to variations in weather and also to annual variations in the biological factors, such for instance as the abundance or scarcity of phytoplankton.

On the basis of thermal and gas conditions in the lower water during the summer, the lakes fall readily into two groups. The first group includes those which are shallow and whose area and exposure to wind are such that the entire body of water is kept in circulation during the summer. Only 27 lakes, however, belong to this class, and they vary in depth from 3 meters to 10 meters. As a result of the complete circulation of the water, thermal and gas conditions were found to be substantially the same from surface to bottom. The lakes of this group contained various amounts of oxygen dissolved in their waters as a result of differences in the amount of decomposition going on and differences in the abundance and photosynthetic activities of the algæ, but in each lake the oxygen conditions were generally the same at all depths. The results show that, during periods of clear, calm weather, the upper 2 meters to 3 meters of water may become supersaturated with oxygen owing to the action of the algæ and that the dissolved oxygen of the bottom water may decrease appreciably as a result of the decomposition going on there, but a brisk wind would soon restore uniform conditions. These lakes showed no other characteristics which require further consideration.

The second group of lakes includes those in which the entire body of water was not kept in circulation during the summer but in which a more or less pronounced thermal stratification was found. Some of the 129 lakes belonging to this group did not differ very widely from those of the first group, since the bottom stratum which did not take part in the circulation was not more than a meter or a meter and a half thick. This condition was found only in the shallower lakes of this class. In the others the cool, lower stratum of water which was not kept in circulation by the wind, varied in thickness from a very few meters to as much as 60 meters, depending upon the depth of the lake. This group is characterized by the fact that there is a more or less pronounced decrease in the dissolved oxygen in this lower stratum of water during the summer. The amount of the decrease varied very much in the different lakes. In some the bottom water contained 75 to 80 per cent. as much oxygen as the surface which was freely exposed to the air; while

in others a layer of bottom water of varying thickness was entirely devoid of free oxygen.

The second group of lakes may be further separated into two divisions for convenience in the discussion. The first comprises those lakes in which the supply of dissolved oxygen in the lower water is not entirely exhausted during the summer, the amount varying from about 80 per cent. of that in the surface water to only a trace; the second division includes those lakes in which the dissolved oxygen is completely exhausted from more or less of the lower water.

It has already been pointed out that the lower water in a thermally stratified lake is cut off from further contact with the air after stratification and hence has no opportunity to obtain a new supply of oxygen from the air until the autumnal overturn. As rule very little if any ground water ever reaches the deeper water of a lake directly and even if it did, it is generally so deficient in oxygen that very little of this gas would be contributed to the lower water from this source. Neither are conditions favorable in the lower water of a deep lake for the photosynthetic activities of the algæ, so no free oxygen will be derived from this source. Hence the summer supply of oxygen in this region is limited to the amount which the water possesses at the time that it becomes stratified. When this supply is once exhausted, this water must remain free of oxygen until the autumnal overturn.

Two factors are responsible for the exhaustion of the oxygen dissolved in the lower water. The living organisms, both plants and animals, which inhabit this region use up some of this oxygen in the process of respiration. But by far the most important factor concerned is the decomposition of organic matter. A small amount is doubtless used in the direct oxidation of dead organic material, but most of it is exhausted in the decomposition which results from the action of bacteria.

The decomposable matter is derived from various sources, but the material which probably affects the largest volume of water is that derived from plankton forms, more especially from the phytoplankton. In general the latter reproduce very rapidly under favorable conditions and live a comparatively short time. Thus when the upper water contains an abundance of phytoplankton it will furnish a constant supply of decomposable material to the lower water. Through the floating devices possessed by these organisms, their specific gravity is reduced so that it is generally only a very little greater than that of water, some forms even being able to remain suspended for several hours in seventy or eighty per cent. alcohol. Forms which possess such a low specific gravity will sink very slowly through the cool, lower water when they die, and this will give opportunity for them to pass through at least the early stages of decay on their downward passage. In this way the supply of oxygen in the lower stratum will be affected not only at and near the bottom but throughout the entire region below the thermocline.

The decomposition of a great deal of phytoplankton in the upper water also sometimes causes a material decrease in the oxygen here, in spite of its free exposure to the air.

The specific gravity of most zooplankton forms is greater than that of phytoplankton forms. Thus they sink more rapidly and their decomposition does not proceed very far before they reach the bottom. For this reason they are probably not such an important factor in exhausting the oxygen supply through decay except at the bottom.

Another important source of decomposable material is the shore vegetation, more especially the leaves of trees. Lakes whose shores are covered with deciduous trees will receive a very large amount of decomposable material in the form of leaves when these are shed in the autumn. They will be blown into the lakes and will eventually sink to the bottom. A few lakes have been found in which the bottom in the deeper portions of the lakes is literally carpeted with decomposing leaves. The decay of this material goes on more or less rapidly at all times and it is a very important factor in removing dissolved oxygen from the bottom water in lakes where it is so abundant.

The shallow water vegetation also contributes its quota of organic material to the deeper water. The larger aquatic plants are frequently torn loose from their moorings in shallow water by the action of the wind and waves, especially in the fall, and carried out to deep water where they sink, thus contributing to the supply of decomposable material on the bottom. In lakes which have very little water shallow enough for such plants, this source of material would not be of very great importance, but in lakes which have large areas of shallow water, such as wide shallow margins for instance, where such plants may thrive in abundance, this would be an important source of organic material.

The rapidity of the decrease of the oxygen in the lower water depends chiefly upon three factors, the quantity of decomposable material, the temperature of the water, and the volume of water below the thermocline. The larger the amount of decomposable matter, the faster will the dissolved oxygen be used up. In a plankton-poor lake, the decrease will be slow on account of the scarcity of organic matter. The higher the temperature of the lower water, the faster will decomposition take place, and consequently the more rapidly will the supply of oxygen decrease. In some lakes the bottom water does not have a temperature of more than 5° to 7° during the summer, while in others it may rise to 13° or 14°. Obviously, of course, the process of decay will proceed more rapidly in the water having the higher temperature and other conditions being the same the dissolved oxygen will decrease more rapidly in lakes whose bottom water has a temperature of 13° to 14° than in those having the cooler water.

Likewise the rapidity of this decrease will depend upon the volume of water below the thermocline because the amount of dissolved oxygen

in this water will be proportional to the volume of water. Also the extent of the oxygen decrease in the lower water, is a function of the quantity of decomposable material contributed to this region, and of the volume of the water.

EXCESS OF OXYGEN

So far only those factors have been considered which are active in using up dissolved oxygen. There are activities going on in the upper water, however, which increase the supply of oxygen in this region. These activities not only aid in keeping the water saturated with oxygen, but under favorable conditions they may result in the supersaturation of certain strata of water with this gas. A few meters of the upper water of Lake Mendota may thus become supersaturated with oxygen under favorable weather conditions, and other lakes show the same phenomenon. The upper water always contains chlorophyl-bearing organisms whose numbers vary from a few hundreds per liter in some lakes to as many as several hundred thousand in others. The number found in any one lake from time to time during the summer varies very widely of course. When exposed to light, these organisms are able to carry on the process of photosynthesis in which carbon dioxide is taken up from the water and broken up into its two elements. The carbon is retained for further use in the plants and the oxygen is liberated, some or all of it passing into solution in the water so that the quantity of this gas may be raised above the saturation point.

In Lake Mendota the maximum amount of excess oxygen was found at a depth of only a meter and a half and such an accumulation of oxygen can take place only during calm weather. A breeze would set this upper water into circulation and it would all be exposed to the air from time to time where the oxygen tension would be lower and the excess would be imparted to the air. Even during calm weather, more or less of the upper water will be disturbed by convection currents on cool nights and will thus be exposed to the air, so that the excess of oxygen will be greatly reduced at least. In this upper stratum, then, the excess oxygen will not be much greater than the amount which the chlorophyl-bearing organisms can produce in a single day, for the disturbances due either to wind or convection currents will prevent the accumulation of a large amount of excess oxygen at so slight a depth. But some lakes have been found in which rather large amounts of excess oxygen accumulated in the upper part of the thermocline. Since the water at this depth is disturbed very little by wind action and not at all by convection currents, it may remain supersaturated with oxygen for a long period of time. The transparency of the water is such in these lakes that the algæ in the thermocline receive enough light to enable them to carry on their photosynthetic activities. As stated above, the water

of this region is affected very little by the wind, so that oxygen is removed only by decomposition, respiration, and the slow process of diffusion. When the algæ are active and the light is favorable, the production of oxygen greatly exceeds the consumption, consequently it accumulates in this region until there is a large excess in some instances.

Several investigators have found an excess of dissolved oxygen in the waters of ponds and lakes during the summer, but the maximum quantity that has generally been found at this season was about 300 per cent. of the amount required for saturation. Both Knights lake and Otter lake have shown larger amounts than this, each rising considerably above 300 per cent. of saturation, but the maximum amounts of this gas have been found at a depth of 4.5 meters in both lakes. At that depth the hydrostatic pressure is about half an atmosphere and this extra pressure would aid materially in holding the oxygen in solution. It is doubtful whether the amount of oxygen could have risen much higher without some of it being liberated in bubbles, and, in fact, it seems probable that some of it escaped in this way even under the above conditions. When this water was pumped up to the surface it effervesced very freely, so it is safe to say that the quantity of oxygen indicated in the results does not represent the entire amount that was present.

CARBON DIOXIDE

Carbon dioxide is readily soluble in water and a water which is freely exposed to the air will contain more or less free carbon dioxide under normal conditions, as this gas is one of the constituents of the atmosphere, being present in the proportion of 3 or 4 parts in 10,000. But only a small amount will be absorbed from the air because it is taken up only in proportion to its partial pressure. The free carbon dioxide of a water, however, will be affected by the presence of chlorophyl-bearing organisms when there is enough light for photosynthesis, and also by the presence of decaying organic matter.

The water of Lake Mendota which receives a sufficient amount of light to permit photosynthesis, is generally well stocked with algæ during the greater portion of the year and their demands for carbon dioxide are greater than the supply of free carbon dioxide which this water obtains from various sources such as the air, the respiration of various organisms, the decay of organic matter, and the ground water. Consequently they draw upon the supply of half-bound carbon dioxide and this results in making the upper water alkaline. The degree of alkalinity varies of course, depending upon several factors, chief among which are the abundance and activity of the algæ, the season of the year, and the weather conditions. As might be expected, it is greatest in summer when the phytoplankton is most active and when this activity is re-

enforced in a measure by that of the submerged aquatic plants growing in shallow water.

A general decline in the alkalinity of the water of the epilimnion began toward the end of September and continued until late October. This decline was due chiefly to four factors. 1. The temperature of the water was falling at this time so that conditions for the summer algæ, chiefly green and blue-green forms, were gradually growing more unfavorable and the rising crop of diatoms was not so active in the process of photosynthesis. 2. As the thermocline was moving down into the deeper water rather rapidly at this time, much water which contained free carbon dioxide was mixed with the alkaline water above, and the result was a tendency to reduce the alkalinity. 3. Strong winds are generally frequent at this season and the circulation of the upper stratum would be more vigorous so that the water would be frequently exposed to the air from which it could absorb free carbon dioxide. 4. The decomposition of organic matter would also furnish free carbon dioxide and much decomposable material was furnished by the lower water when it was mixed with the upper. On the basis of the above results, however, all acidity has been attributed to the presence of free carbon dioxide.

RELATION BETWEEN CARBON DIOXIDE AND OXYGEN

In the process of photosynthesis, chlorophyl-bearing organisms consume a volume of carbon dioxide equal to the volume of oxygen produced but in no case has this direct relation been observed in the lake waters, as a result of the activities of such aquatic organisms. Other processes which affect the quantity of both gases are taking place simultaneously and these tend to modify and obscure the results of the photosynthesis. When this action takes place in the upper stratum which is kept in circulation by the wind, this water will be exposed to the air from time to time and will part with some of its excess oxygen, if the amount rises above the saturation point. Also when exposed to the air, this water will have an opportunity to obtain carbon dioxide.

In the thermocline region and below, however, the water is not subject to such disturbances by the wind, and if oxygen is liberated in this water, practically none of it will be lost in this manner. But the quantity of these two gases dissolved in the lower as well as in the upper water will be affected by the respiration of living organisms and the decay of organic matter. Thus, they will add to the complexities which make it difficult to trace the relationship between carbon dioxide consumption and oxygen production, for both processes take place in the stratum in which photosynthesis is in progress.

The largest amounts of excess oxygen have been found in small spring lakes, that is, lakes which receive a very large portion of their water

supply from springs. This spring water contains an abundance of available carbon dioxide which could be utilized by the chlorophyll-bearing organisms, but just how this inflowing water could furnish the required amount of carbon dioxide without the oxygen content of the supersaturated stratum being affected thereby, is not evident, for this spring water is very generally deficient in oxygen. So far as these results go, this must be left as one of the unsolved problems at present. It has not yet been possible to follow closely an excess oxygen phenomenon through all stages of its development and disappearance and such a study would doubtless throw some light on this relation between carbon dioxide and oxygen.

In observations made on Lake Mendota in September, 1908, it was found that there was a general tendency for the alkalinity to increase as the quantity of oxygen increased, but there were appreciable variations. Sometimes the loss of half-bound carbon dioxide was greater than the gain in oxygen and sometimes it was less. In the other lakes in which excess oxygen has been found, it may be said in general that the carbon dioxide decrease (both free and half-bound) by no means accounted for the quantity of oxygen produced.

Neither is it possible to trace any direct relation between the oxygen consumption in the lower water, due chiefly to the decay of organic matter, and the increase of free carbon dioxide there. Some of the oxygen is used up in the formation of water during the process of decay and carbon dioxide is formed in excess of the amount of dissolved oxygen consumed, for this gas is freely formed even when decay takes place under anaerobic conditions.

NITROGEN

Nitrogen is such an inert gas that the quantity dissolved in lake waters is not affected by the various chemical and biological processes which take place in a lake. For this reason there was no hesitation in discontinuing its determination for the purpose of making a more thorough study of the oxygen. The dissolved nitrogen varies somewhat in amount because it is more soluble in cold than in warm water; hence the maximum amount is found in winter. As the water becomes warmer in spring and summer, the quantity decreases so that by the last of June the upper stratum usually does not contain more than 65 to 67 per cent. as much as in winter. During the vernal period of circulation, in lakes where this circulation is complete, the water at all depths remains substantially saturated with nitrogen as long as this complete circulation lasts. During the summer, the upper water which is kept in circulation by the wind and freely exposed to the air will also be found nearly or quite saturated with this gas. In the thermocline region, however, and below, the water may contain an excess of nitrogen.

This excess may have been produced in either or both of two ways. The lower water will be substantially saturated with nitrogen at the end of the vernal period of circulation. As the season advances the temperature of this water rises more or less, hence its capacity for this gas decreases. This would tend to liberate some of the nitrogen; but the hydrostatic pressure at this depth and the lack of circulation tend to prevent its escape. Likewise, the rate of diffusion is so low that very little will be lost in this manner. As a result, the nitrogen remains in the lower water and produces supersaturation. Ground water frequently contains an excess of nitrogen and some of the excess in lake water may come from this source. It seems probable that some of the excess nitrogen found in the lower water of Otter lake is due to ground water. This lake is fed very largely by springs, but no nitrogen determinations have been made for any of them. The water of a spring about half a kilometer away on Hicks lake showed an excess of about 18 per cent. of nitrogen and the spring water entering Otter lake doubtless contained a similar excess of nitrogen.

METHANE

Methane is one of the products resulting from the slow decay of organic matter. It is frequently formed in the decomposition which takes place at the bottom of ponds and marshes and for this reason it is often called marsh gas. Generally a great deal of organic material decays in the lower water and at the bottom of lakes and frequently the conditions are favorable for the formation of methane. In several lakes the residue which remained after the removal of the carbon dioxide and oxygen was large enough to make it evident that this residue was composed of something besides nitrogen. Accordingly tests were made for the purpose of determining whether any hydrocarbon gases were present and, when evidence of their presence was found, analyses were made to determine the kind and quantity present.

The maximum amounts of methane have been found in the bottom waters of Beasley and Garvin lakes. These lakes are small and well protected from winds so that the vernal overturn may be more or less incomplete. As a result the bottom water does not receive a very large supply of dissolved oxygen in the spring and this small stock is soon exhausted by the decay of the large amount of organic matter that is found on the bottom of these lakes. Decomposition then proceeds under anaerobic conditions, which are most favorable for the production of methane. These favorable conditions continue for a period of about five months and in Garvin lake so much methane and free carbon dioxide are generated during this time that in late August and in September many bubbles of these gases may be seen rising to the surface. On September 13, 1905, a sample of gas from the bottom water of

Garvin lake contained 38.5 cubic centimeters of methane per liter, and one obtained from Beasley lake on August 21, 1906, contained 28.9 cubic centimeters. In its vertical distribution the quantity of methane increases with increasing depth, the largest amount being found at the bottom, where the greatest amount of decomposition takes place.

CARBON MONOXIDE

While gasometric analyses were being made during the summers of 1905 and 1906, some tests were made to determine whether any carbon monoxide was held in solution in the water, especially in the bottom water of lakes where anaerobic decomposition was taking place. After the removal of the oxygen and carbon dioxide, the residue was transferred to a pipette containing cuprous chloride for the removal of any carbon monoxide that might be present. The contractions in volume obtained by this method were rather irregular and some of them seemed unusually large. This led to the conclusion that the results obtained by this method were not very reliable.

HYDROGEN

Many tests have been made for hydrogen, but it was not found in any of the residual gases examined. The palladium method, however, was used, and this method is not delicate enough to detect very small amounts of this gas. It seems probable that some hydrogen may be liberated in the process of anaerobic decomposition, but if such is the case, it is in such minute quantities that it cannot be detected by the palladium method. With a method for hydrogen as delicate as the iodometric one for carbon monoxide, its presence in the lower water could doubtless be demonstrated.

HYDROGEN SULPHIDE

"An odor like that of sulphureted hydrogen must not be taken as proof positive of the presence of that gas in a water, inasmuch as mixtures of sundry hydrocarbons will often greatly mislead the sense of smell." Tests for hydrogen sulphide on several lakes where the water had such an odor gave abundant confirmation of the truth of this statement. An odor resembling that of sulphureted hydrogen is very generally found in bottom water which possesses no dissolved oxygen, yet chemical tests did not indicate the presence of this gas in many instances, especially if anaerobic decomposition had been going on for only a comparatively short time. In late summer, however, in lakes where anaerobic decomposition has been in progress for some weeks in the lower

water, more or less hydrogen sulphide may be found in this region. During the summer of 1908, the lower water of a number of lakes was tested for hydrogen sulphide by the iodometric method. While these tests indicated the presence of this gas in the majority of the waters tested, yet it appeared only in very small amounts.

The presence of so much decomposing organic matter in the lower water raised a query as to the reliability of this method for such waters. In order to answer this question some determinations were made in duplicate, using both the iodometric and a colorimetric method. While the latter indicated the presence of hydrogen sulpide in all waters when it was so indicated by the iodometric method, yet the colorimetric gave results uniformly lower, showing only 14 to 33 per cent. as much as the iodometric. This led to the suggestion that some organic compounds of sulphur may be present which affect the iodometric determinations but not the colorimetric and thus give results somewhat higher than they should be.

It may be said that these results furnish conclusive evidence of the formation of hydrogen sulphide in the lower water under the conditions indicated above, but they show that only very small amounts of it are formed. It was found only in water which contained very little or no dissolved oxygen.

ORGANIC MATTER

It has already been pointed out that more or less decomposable organic matter is found in the water of the lakes and that such material is derived from the plankton, from the larger aquatic plant and animal forms, and also to a certain extent from the shore forms. The effect of the decomposition of this material on the oxygen dissolved in the water has also been discussed. But this decomposing matter plays another very important rôle. When this organic material breaks down, the first step in the process is the oxidation of the carbon, hydrogen, and nitrogen therein to carbon dioxide, water, and ammonia. If liberated in a region where photosynthesis takes place, this carbon dioxide contributes to the stock of this gas which may be drawn upon by chlorophyl-bearing organisms. The free ammonia may be used up directly by the algæ, or it may undergo further oxidation, being converted first into nitrous acid, forming nitrites and ultimately into nitric acid forming nitrates. These nitrites and nitrates constitute a very important source of food for aquatic plants. This supply of nitrogen compounds is increased by that derived from other sources. Rainwater, for example, obtains ammonia from the air and the water which sinks into the soil comes into contact with and dissolves some of the nitrogen salts, which are then carried along with it and eventually reach the lake.

Plants require nitrogen in an available form for their metabolic processes and the free floating aquatic forms must obtain their supply of this substance from the nitrogen compounds dissolved in the water. Therefore, the scarcity or abundance of available nitrogen in the water of a lake is doubtless a very important factor in determining the scarcity or abundance of the phytoplankton in such lake, just as the available nitrogen in a soil bears a very close relation to the size of the crop which will grow thereon. This then may be one of the very important factors which are responsible for the characteristic differences in the phytoplankton content of different lakes. As yet, however, no studies of this nature have been taken up on lakes which show striking differences in phytoplankton.

DISTRIBUTION OF THE PLANKTON

One may safely say that the most important element in the environment of strictly aquatic, free floating or free swimming organisms, is the water which they inhabit. This factor of their environment is not the same for all bodies of water, since the various waters possess very different chemical characteristics, as has already been indicated. In fact, this is quite true of the same body of water at different periods, for each passes through a series of chemical changes during the different seasons of the year. Given then, such variations in this important element of the enviroment, it may be well to consider some of the causes and results of these variations from a biological standpoint. It may be well to state here that the following discussion of this question is only a partial one, as it is confined almost entirely to the dissolved gases. Other factors are involved also, but, up to the present time, it has not been possible to collect enough data to permit a more extended consideration of them.

The relations between chemical and biological conditions in lakes present two chief phases which are closely allied and interwoven, but which it may be well to separate for purposes of discussion. The first of these phases is the effect of living organisms on the chemical condition of the water and the second is the consequent effect of the chemical status of the water on the living organisms inhabiting it. Since the first phase has been more or less fully presented in previous chapters, it is not necessary here to give any extended discussion of this question. Attention has been called to the fact that the living organisms of a lake as well as of the immediate environs contribute decomposable matter to the water and that the decomposition of these organic substances affects the chemical conditions in a marked degree, especially with respect to some of the dissolved gasses in the lower water of lakes that are thermally stratified. Some or all of the dissolved oxygen in the lower stratum is used up in the process of decay and carbon dioxide

and ammonia are formed. The latter is then oxidized to nitrous and nitric acids in the presence of free oxygen, which combines with other substances to form nitrites and nitrates. Frequently, also, methane is formed and in some instances hydrogen sulphide and carbon monoxide. In the process of respiration of both animal and plant forms, dissolved oxygen is removed from the water and carbon dioxide is contributed to it. The various excretions of living organisms, also, tend to alter chemical conditions.

On the other hand, chlorophyl-bearing organisms remove free or half-bound carbon dioxide from the water in their photosynthetic activities and liberate oxygen. The atmospheric tension of the former gas is so slight and its rate of diffusion is so low that it does not pass into the water readily from the air and it diffuses upward very slowly from the lower water, which may contain an abundant supply of this gas in a free state. Consequently it frequently happens that not enough free carbon dioxide passes into the stratum in which the chlorophyl-bearing organisms are most active, to supply the needs of any considerable number of them and as a result the free carbon dioxide may be largely or entirely exhausted from a stratum of water which varies in thickness in different lakes. The consumption of carbon dioxide may proceed beyond the point of neutrality or complete exhaustion of the free gas and some of the half-bound is often removed, thus making the water more or less strongly alkaline. It has been found that in lakes which have either a hard or a moderately hard water, the upper stratum very generally becomes alkaline in early spring and continues so until the autumnal overturn. Indeed, it has been noted that more or less of the upper water in Lake Mendota may remain either neutral or alkaline throughout practically the entire year. In the hard-water lakes the alkalinity may reach a point where some of the normal calcium carbonate will be precipitated, thus forming a layer in which the combined carbon dioxide will show a pronounced decrease. Alkaline strata have also been found in lakes which have very soft water.

At the same time that carbon dioxide is being used up, an equal volume of oxygen is being liberated. Where conditions are favorable for the accumulation of this oxygen, the water will be found supersaturated with it, the amount of supersaturation reaching 364.5 per cent. in Knights lake. As yet, however, it has not been possible to trace any direct correlations between the amount of carbon dioxide consumed and the quantity of oxygen liberated. And it may be said further that only in a very general way has it been possible to trace any quantitative relation between chlorophyl-bearing organisms and either alkalinity or high oxygen.

Turning now to the second phase of the subject, which is the relation of chemical to biological conditions, the effect of the former on the animal forms will be considered first and on the plant forms later.

Those lakes which are so shallow that the entire body of water is kept in circulation by the wind during the summer, may be disregarded. The deeper lakes, those which show a thermal stratification in summer, may be divided into three classes. To the first class belong those lakes which have an abundance of free oxygen in all of the water below the thermocline during the summer, such for example as Green lake. The second class includes those lakes in which the free oxygen entirely disappears from a portion of the cool water below the thermocline during the summer; and the third class includes those lakes in which practically all of the water below the thermocline is devoid of free oxygen in late summer.

During the vernal overturn and circulation the plankton organisms are distributed almost or quite uniformly from surface to bottom in all three classes of lakes, with the exception of those in which these processes are not complete. As soon, however, as the bottom water begins to lag behind in the process of circulation a differentiation in the vertical distribution of these organisms sets in. The phytoplankton forms are the first to show a marked change. In the deeper lakes, of course, the light conditions in the bottom water are not favorable and soon after this water ceases to take part in the general circulation, its phytoplankton population begins to decrease. At the same time the conditions in the upper stratum are becoming more favorable as a result of the increase in the temperature of the water and the phytoplankton population of this region increases. The net result of these conditions, then, is a marked change in the distribution of these organisms, the lower stratum being scantily populated by them while the great majority occupy the upper strata. The animal forms, however, which are not influenced so markedly by light conditions may still continue to be fairly uniformly distributed from surface to bottom. But as summer advances the vertical distribution of the animal forms (that is, those which do not bear chlorophyl and are not therefore dependent in any way on light) becomes different in the three classes of lakes mentioned above.

SENSITIVENESS TO LACK OF OXYGEN

The various zooplankton forms show different degrees of sensitiveness to the lack of oxygen in lake waters. It would seem that such active organisms as the plankton crustacea would require a rather large amount of free oxygen, but it has been found that they are able to occupy water which contains only a very small amount of this gas. *Diaptomus* is much more sensitive than *Cyclops* and is rarely found in water which contains less than 0.2 cubic centimeter to 0.3 cubic centimeter of oxygen per liter, while *Cyclops* may be found in considerable numbers in water which contains only 0.1 cubic centimeter or even less.

In one experiment some specimens or *Cyclops bicuspidatus* which had just emerged from their encysted state, lived for several hours in water which contained no free oxygen whatever. Also in Rainbow lake on October 22, 1909, specimens of this *Cyclops* were found at depths where there was no dissolved oxygen. These specimens were immature and had doubtless recently come out of the cocoon. In view of the fact that this form lives several weeks during the summer in an encysted stage, in water which does not contain dissolved oxygen, it is not so surprising, perhaps, that it shows such a very low degree of sensitiveness to lack of oxygen when it is not in the encysted stage. An ostracod, also, as indicated on a subsequent page, is able to live in water which contains no dissolved oxygen.

The copepod nauplii are able to live where only a very small amount of free oxygen exists. In a very few instances they have been found in water which contained only a trace of oxygen, but generally they do not occupy water which possesses less than 0.1 cubic centimeter.

The *Cladocera* are more sensitive to lack of oxygen than the *Copepoda*. *Daphne longispina* var. *hyalina* and *D. pulex* may be found in considerable numbers in water which has only 0.2 cubic centimeter to 0.25 cubic centimeter of oxygen per liter but healthy looking individuals are practically never found in water containing less than this amount. *Daphne retrocurva*, *Diaphanosma*, *Chydorus*, and *Bosmina* are found almost entirely in water which has a fairly large amount of dissolved oxygen. Only rarely are they taken in water which possesses less than 0.5 cubic centimeter of free oxygen and they are most abundant in water which is nearly or quite saturated with this gas. These forms, however, are very generally limited to the region above the thermocline even in lakes where there is an abundance of oxygen below this depth and it seems probable, therefore, that other factors play a more important rôle than oxygen in determining their vertical distribution.

In one instance (Beasley lake, Apr. 22, 1909) a fairly large number of rotifers was found at two depths where only a trace of oxygen was present but rarely has any considerable number been found in water containing less than 0.1 cubic centimeter of free oxygen per liter, and more often, they are very scarce when the amount falls below 0.15 cubic centimeter to 0.2 cubic centimeter.

It will be noted in some of the accompanying diagrams that some forms show a marked increase in numbers in the region just above the water which is devoid of dissolved oxygen. These aggregations are generally found in water which contains from 0.15 cubic centimeter to 0.8 cubic centimeter of dissolved oxygen per liter. Nauplii exhibit this phenomenon most frequently, but rotifers, *Cyclops*, *Daphne longispina*, and *D. pulex* have occasionally shown the same phenomenon.

Corethra larvæ, apparently those of *Corethra punctipennis*, are able to occupy with apparent impunity, water which contains no dissolved

oxygen. In fact, they seem to prefer this region in the daytime as they are almost invariably found here when they inhabit such lakes. It is not known definitely whether the two pairs of air-sacs possessed by these larvæ have any respiratory function or not; but in this case, one can readily see how they may serve a very important function by acting as reservoirs for oxygenated gas. But it will be shown below that other animals which are more or less active, and which do not possess any such reservoirs, are able to live for two or three months in a medium which contains no free oxygen. Therefore it is not necessary to assume that these larvæ carry a supply of oxygen with them when they move down into the water which is devoid of this gas, for it may be that they too are able to live by intra-molecular respiration for some time.

As yet no thoroughly satisfactory reason can be assigned for the migration of these larvæ to this region in the day time. They react negatively to light, as they move down from the upper water early in the morning and remain in and below the thermocline during the day. At night, however, they are frequently found at the surface. They descend to depths of 12 meters or 15 meters in the daytime in lakes which have a very low transparency, that is, in some where a Secchi's disc disappears from view at a depth of two meters or even less. This seems to indicate that light is not the only factor involved, for it scarcely seems probable that light alone could be responsible for such a large depth of migration in lakes which have such a low transparency. It appears, then, that other factors are involved which are still unknown.

In lakes whose lower water contains no dissolved oxygen, these larvæ are the only regular inhabitants of such water, so they would be free from enemies here. On the other hand, however, they remain in the lower water in the daytime in lakes where there is enough oxygen to enable their enemies to occupy this region also. In North Turtle lake, for example, some specimens of *Lota maculosa* were obtained from the lower water and the stomach of one contained about 200 *Corethra* larvæ, while stomachs of other specimens contained from 10 to 100 larvæ. In view of this fact, then, one cannot say that the larvæ more down into this region in such lakes to avoid their enemies.

No evidence has yet been found which indicates that a chemical factor is involved. This diurnal migration has been found in some lakes in which the water above the thermocline gave an alkaline reaction while that below gave an acid reaction on account of the free carbon dioxide present. It has also been noted in other lakes in which the water contained free carbon dioxide from surface to bottom so that it gave an acid reaction at all depths and in lakes which have soft as well as in lakes which have hard water.

In Beasley lake, another animal was found which occupied the bottom water regularly during the summer of 1909, where there was little or no free oxygen. It was the bright green *Stentor igneus* Ehrb.

This protozoan has not been noted in any other lake, and the fact that Beasley lake is comparatively shallow (14 meters) and the water generally has a fairly high transparency, suggests that this *Stentor* may receive enough light during the daytime to enable it to manufacture a sufficient amount of oxygen for its own respiration.

Several forms have been found in the muddy ooze at the bottom although there was no free oxygen in this region. These forms have been studied chiefly in Lake Mendota and the following discussion applies particularly to this lake. The protozoa were represented by the largest number of forms. Living, active representatives of sixteen genera have been noted, *Pelomyxa, Difflugia, Colpidium, Gyrocoris, Peranema, Coleps, Loxophyllum, Paramecium, Prorodon, Lacrymaria, Uronema, Monas, Metopus, Spirostumum, Loxodes,* and *Stentor.* All of the individuals representing these genera were perfectly normal so far as could be determined. They showed no evidences of unusual vacuolation, or any other signs of ill effects resulting from the anaerobic conditions under which they lived. Some of the parasitic protozoa live under practically anaerobic conditions constantly, so it is not surprising, perhaps, that the above forms should adapt themselves to such conditions when necessary. These anaerobic conditions exist in Lake Mendota for a period of about three months each summer, and it has been found that these protozoa are as numerous and as active toward the end of this period as at the beginning. Apparently, then, these organisms are able to carry on their life processes just as well under anaerobic as under aerobic conditions.

Higher invertebrates were also found in this muddy ooze. The worms were represented by specimens of *Tubifex, Limnodrilus,* and *Anguillula;* the rotifers by *Chætonotus* and *Philodina;* the crustacea by an ostracod belonging to the genus *Candona* and by encysted specimens of *Cyclops bicuspidatus;* insect larvæ by a large red chironomid larva; and the mollusca by *Corneocyclas idahoensis.*

Some observations were made to determine how active some of these forms are under anaerobic conditions. Muddy water containing them was pumped into glass jars that could be sealed and kept air tight. This muddy water was pumped through the jars so that they could be thoroughly flushed and all of the material removed that had been exposed to the air. The jars were sealed immediately after the material was obtained and they were then taken to the laboratory and placed in a refrigerator in order to keep the temperature about the same as that of the mud in the bottom of the lake. They were kept at a temperature of 13° to 15°, which was 1.5° to 2.5° above that of mud at the time the material was obtained. The jars were carefully removed from the refrigerator from time to time and examined, in order to determine how active the various animals were.

The worms were as active under anaerobic as under aerobic conditions.

So far as could be determined, they were not affected in the least by the absence of free oxygen. It has been found that some parasitic forms which live under essentially anaerobic conditions have a very high glycogen content, but no determinations have yet been made to ascertain the relative proportion of glycogen in these non-parasitic forms.

With respect to high oxygen, it may be said that water which is supersatured with this gas seems to have no effect whatever on the vertical distribution of the various zooplankton forms. They are neither attracted nor repelled by such a stratum of water. The diagram for Knights lake on Aug. 25, 1909, shows how little the high oxygen affects the distribution of these organisms.

Some tests were made on fishes in order to ascertain how the lower water, which contained no free oxygen, would affect them. Perch (*Perca flavescens*) and crappies (*Pomoxis*) were used for this purpose as they are very hardy. Aquaria and specimens of these two fishes were taken out in a boat on Lake Mendota and some of the lower water free from dissolved oxygen was pumped into an aquarium, the discharge end of the hose extending to the bottom of the aquarium so as to expose the water to the air as little as possible. The aquarium was well flushed and then a fish was quickly introduced. In nearly all cases the specimens turned ventral side up in 20 to 30 seconds after they were placed in this water, and specimens which remained in the water died in a few minutes. If they were removed, however, after two or three minutes in aerated water, they quickly revived. These results only confirmed what had been taken for granted before performing the experiments, that is, that the lower water is uninhabitable for fishes when it contains no dissolved oxygen.

Experiences with Fish.—No further experiments have yet been made to ascertain the resistance of fishes to lack of oxygen. König found that he could keep fish (kind not specified) in water which contained 2.95 cubic centimeters and 1.38 cubic centimeters of dissolved oxygen per liter without any apparent ill effects. Thorner found that a fish epidemic was caused by the absence of free oxygen. Hoppe-Seyler and Duncan state that the trout which were kept from one and a half to two and a quarter hours in water having only from 0.98 to 1.71 cubic centimeters of oxygen per liter showed marked signs of dyspnea. Paton in experiments on young rainbow trout, found that a fall in the amount of dissolved oxygen below one-third of the normal amount, *i.e.*, below 2 cubic centimeters per liter of water, is prejudicial and generally fatal. Some individuals, however, were able to sustain life for long periods in water which contained only minimal traces of dissolved oxygen.

Knauthe found that carp kept for an hour and twenty minutes in water which contained 1.33 cubic centimeters of oxygen per liter did not show any signs of dyspnea, while others became dyspneic in water

containing from 2 cubic centimeters to 3.1 cubic centimeters of this gas.

Only two instances have been noted which give some notion of the resistance of any species of fish to the lack of dissolved oxygen. The Mackinaw trout (*Cristivomer namaycush*) has a peculiar geographical distribution in the lakes of northern Wisconsin and some observations were made for the purpose of ascertaining, if possible, the cause of this peculiarity. In the course of this work, Trout lake, in which the Mackinaw is fairly abundant, was visited in early September, 1906. This lake consists of two parts connected by a comparatively narrow but deep channel, and both parts have a maximum depth of about 30 meters. Some gill nets were set on the bottom in the deepest water of the south part, that is, in water 28.5 meters to 30 meters deep, and in 24 hours six trout were obtained. At the time the nets were raised, some samples of the bottom water at this point were taken, and these showed that the water at 29 meters contained 0.9 cubic centimeter of dissolved oxygen per liter and at 27 meters there were 2.1 cubic centimeters.

The position of the trout in the nets indicated that they were within one meter, or perhaps less, of the bottom and therefore in water which did not contain more than about 1 cubic centimeter of dissolved oxygen per liter and very probably less. Also, on September 12, 1909, six specimens of a white-fish were obtained at a depth of 67 meters in Green lake, where the water contained but very little more than 1 cubic centimeter of oxygen per liter. It is impossible to say just how long individuals of these two species of fish could remain with impunity, in water with such a relatively small amount of oxygen, but the facts seem to warrant the conclusion that they do not hesitate in the least to enter water which contains as little as 1 cubic centimeter of dissolved oxygen per liter, or perhaps even a little less than this amount.

The inability of fishes to occupy water which contains no free oxygen means that their vertical distribution is very much restricted in some lakes in summer. In the smaller lakes which are well protected from winds and which contain much decaying organic matter the dissolved oxygen may entirely disappear below a depth of five meters or six meters in late summer. In such lakes, then, the fishes would be restricted to a warm, upper stratum only five meters or six meters thick. Even in so large a lake as Mendota, which has an area of about 39 square kilometers, there is practically no dissolved oxygen below a depth of 10 meters or 12 meters in August and early September. As this lake has a maximum depth of only about 25 meters this means that about half the maximum depth of the lake is uninhabitable for fishes at this time. Scarcely more than a third of the maximum depth of some lakes is habitable for fishes in late summer.

Thus it will be seen that the oxygen condition of the lower water may be a very important factor in determining the geographical distribution

of a species of fish. Such a fish as the Mackinaw trout, for instance, which requires cool water during the summer, would not find conditions favorable for it in a lake where all of the dissolved oxygen disappeared from the cool lower water during the summer. Consequently it would be limited to the lakes which have cold water with enough free oxygen to supply its needs. This fact is of very practical importance in the introduction of this species of trout or of species of whitefish into new waters. A determination of the quantity of dissolved oxygen in the cool, lower water of a lake in the month of August will show whether the introduction of these fishes is likely to prove successful or not.

Plankton organisms, either directly or indirectly, constitute a very important element of the food of most fishes at some stage of their development; in fact, it has been asserted that the production of fish is closely correlated with the amount of plankton produced by a lake, or stream. But some of the foregoing results show that this statement must be modified somewhat for lakes. It has been pointed out that plankton is a very important factor in determining the oxygen condition of the lower water since it furnishes a large amount of decomposable matter. Beyond a certain limit, then, an increase in the amount of plankton would tend toward a decrease in the production of fish in lakes, more especially those species which live in the cool lower water in the summer, rather than an increase, because it would make conditions unfavorable for them in the lower strata. The decompensable matter derived from a very large growth of plankton would use up the dissolved oxygen in the lower water, thus making conditions unfavorable for fishes which prefer cool water and also causing a very considerable restriction in the vertical distribution of even those which are able to live in the warm upper water. So far as oxygen conditions in the lower water are concerned, then, a lake that is poor in plankton would be best adapted to fish life in that region, but the question of food now enters as a factor of equally great importance. Therefore the quantity of plankton that is best adapted to fish life in a lake is that which will give the maximum amount of food and still not furnish enough decomposable material to the lower water to exhaust all of its dissolved oxygen and render this region uninhabitable for fishes.

PRACTICAL ACCOMPLISHMENTS AT LEADING LAKE CITIES

Although more than 25 years have gone by since the Drainage and Water Supply Commission recommended the Chicago drainage canal to free Lake Michigan near the local waterworks intake of sewage, and to remove nuisances in the Chicago river and its branches, progress has not been decisive at other places in the treatment of sewage entering the Great Lakes. As already described at length, Chicago has had the drainage canal in service

since January, 1900. But even now some of the suburban areas adjoining Chicago discharge sewage into the lake and the same is true of some of the nearby cities and towns in Indiana, particularly in the territory drained by the Calumet river.

Buffalo, N. Y., for many years has had an intercepting sewer to protect the greater portion of its river front and especially its water works intake. All of the sewage does not now reach this interceptor which discharges into the Niagara river below the old water works intake.

Milwaukee, Wis., installed over 20 years ago a flushing tunnel to allow sufficient lake water to be pumped into the Milwaukee river to eliminate nuisances in the lower reaches of the river in the city.

At various cities along the lakes there has recently been considerable discussion as to improved sewage disposal. Several elaborate and comprehensive reports have been made and works are actually under construction at Toronto, Canada.

The Lake Michigan Pure Water Commission, comprised of officials of the principal cities and states bordering upon this lake, has collected information and prepared numerous papers urging improvements in this field of sanitation. Recently the the city of Cleveland, Ohio, has taken active steps for increased co-operative effort in this direction. At a session of the International Congress of Municipal Hygiene held at Chicago on Sept. 29, 1911, there was formed "The Great Lakes International Pure Water Association." It is proposed to have a membership of about 60, including two representatives from the United States and Canadian governments, a representative of the United States War Department, one from the United States Marine Hospital Service, two from each state or province borderng on the lakes, and representatives of various cities on the basis of one for each 200,000 of population or fraction thereof.

At the meeting in question considerable discussion was given to available information and particularly as to the policy to be adopted. The delegates passed the following resolution:

That the chairman of this meeting be instructed to communicate to the principal national authorities of the United States and Canada that it is the opinion of the health officers and other sanitarians here assembled that no city should be allowed to pour untreated sewage into the waters of the Great Lakes in any case where the water supply would be injured; that harmful trade wastes should not be allowed to be brought into such waters; and that boats plying these waters should

be required to make adequate provision for the disposal of their sewage.

The medical men present seemed to favor strongly the thorough purification of all sewage, whereas the engineers present endeavored to point out the wisdom of treating each problem on its merits, and purifying the sewage little or much as occasion required. This viewpoint, coupled with the importance of proper treatment of each public water supply, as distinguished from wholesale sewage purification regardless of cost with respect to the benefits secured, was in the minority. The resolution above quoted was passed after some modification of the original draft and with the question of the degree of treatment of the sewage left in abeyance.

SEWAGE POLLUTION OF LAKE ERIE

Recently the sanitary condition of Lake Erie as regards sewage pollution has been studied by Dr. Allan J. McLaughlin as set forth in *Bulletin* 77 of the Hygienic Laboratory, Public Health and Marine Hospital Service of the United States, July, 1911. It records many interesting features of the problem as it now stands and indicates that improvements are needed at several places. The general conclusion is as follows:

Sewage pollution of Lake Erie must be controlled. The zone of polluted water should be lessened and not widened. No crude sewage should be discharged into the lake without treatment. Existing faulty sewer systems should be eliminated as rapidly as engineering and economic problems connected with the change can be solved. Inasmuch as the development of these sewer systems has extended over a great number of years and their existence today represents capital invested, their elimination will be correspondingly slow. In the meantime cities taking their water supplies from the Niagara river or from Lake Erie should by filtration, treatment, or both, render those supplies safe for drinking purposes.

We shall not enter further into this question of policy as to needed betterments, which is already under considerable control at the hands of the sanitary authorities of the states and provinces bordering upon the lakes. We will briefly outline the present status of the sewage disposal question at a number of the leading lake cities.

TORONTO, CANADA

Since the Chicago investigation of 1886 the city of Toronto has given most active attention to the question of sewage treat-

ment. In 1889 Messrs. Rudolph Hering and Samuel M. Gray recommended that the sewage be collected by a proper system of interceptors and after suitable screening be dischargd in deep water through a submerged outfall pipe entering the lake some distance east of the city limits. Numerous engineering reports during the past 20 years have been made upon this question. In 1908 funds were voted, not only for sewage works involving sedimentation tanks and an outfall sewer into deep water of the lake, but also for a water filtration plant.

The sewage works comprise grit chambers and a modified form of Dortmund tank to provide clarification with a detention period

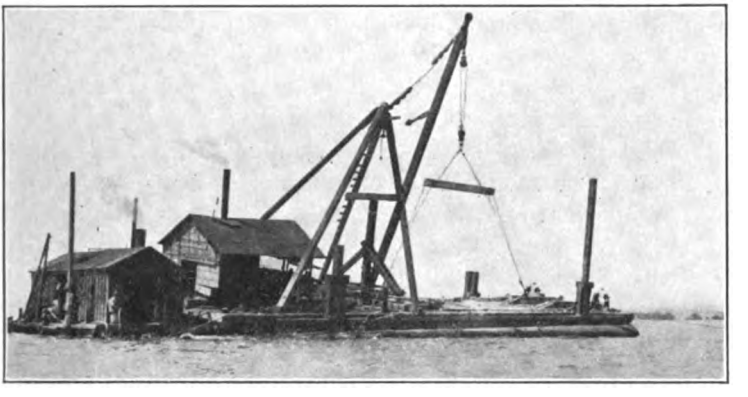


FIG. 8.—Laying outfall sewer, Toronto, Ont.

of about 3 hours. It is proposed to remove the sludge at frequent intervals and use it for filling low land adjoining the lake front, mixing it with alternate layers of earth or street sweepings. The plans were passed upon in 1909 by Messrs. Rudolph Hering of New York City and John D. Watson of Birmingham, England. They advised that satisfactory results would follow as to freedom from nuisance. Mr. Rust states that the dispersion of the sewage will be in 23 feet of water at least 3200 feet from the shore of the lake through 4-inch holes spaced 8 feet apart on both sides of the pipes over a distance of 500 feet. The water supply is drawn from a depth of about 55 feet some five miles from the sewage outfall. (See Fig. 8, furnished by the courtesy of Mr. Rust.)

A review of the Toronto situation, including the conclusions of Messrs. Hering and Watson's report, is outlined by Mr. C. H. Rust, City Engineer of Toronto, in a paper before the American

Society of Municipal Improvements, Vol. XVII, 1910. Mr. Rust has also contributed in his various Annual Reports several special reports on the Toronto sewage question, coupled with records of several investigations of important European sewage plants. Details of the Toronto sewage works may also be found in the *Engineering Record* of Mar. 18, 1911, and *Municipal Journal and Engineer* of Oct. 26, 1910. The population of Toronto in 1911 was about 400,000.

CLEVELAND, OHIO.

In 1895 a commission, comprising Messrs. Rudolph Hering, George H. Benzenberg and Desmond Fitzgerald, was called in to advise with respect to improved sewage disposal for Cleveland, Ohio. It was recommended that an intercepting sewer be built, the sewage after screening to be discharged into deep water of Lake Erie through a submerged outfall, with multiple outlets, extending at least one-half mile from the lake shore and ten miles distant from the water works intake. The details are summarize in *Engineering News* of Feb. 20, 1896.

In 1904 a serious epidemic of typhoid fever broke out at Cleveland and the question of the pollution of the water of Lake Erie in that neighborhood was investigated at length by Mr. George C. Whipple. His report is a valuable one to consult as to a number of important details, particularly as to the extent of the sewage "fields" in a large lake in front of a city discharging sewage into the lake. It is reviewed in the *Engineering Record* of Nov. 10, 1906. He concluded that filtration of the water supply was not then needed, but would be in the near future.

Dr. Allan J. McLaughlin in his recent report above-mentioned, states that all of Cleveland's sewage goes directly or indirectly into the lake. Fifty-two per cent. of it is discharged into the Cuyahoga river. Forty per cent. is discharged into Lake Erie through the submerged outfall of the main interceptor which extends for some ten miles or so along the lake shore. This main interceptor will ultimately take all of the city's sewage according to present (1911) plans. The remaining 8 per cent. is discharged at West 57th street into the harbor. That portion of the main interceptor lying west of the Cuyahoga river is completed and will be extended under the river to join the eastern portion. Other proposed interceptors will eventually take all the sewage from

the river and deliver it into the main interceptor. Some sewage from the low-lying district along the river will have to be pumped into the main interceptor. The old sewer outlets will then serve as storm-water outlets. The new water works intake is about 8.2 miles west of the submerged outfall of the main interceptor.

Sewage disposal as now carried out at Cleveland (population 560,663 in 1910) is not wholly satisfactory from the standpoint of nuisances along the lake beach, nor as regards the quality of the public water supply when used in an untreated condition. Mr. R. Winthrop Pratt was recently engaged by the city to make a careful study of the sewage problem as related to the water supply. A summary of his preliminary report is given in *Engineering News* of Feb. 8, 1912, as follows:

(1) The intercepting sewer system planned in 1895 has been about half completed as regards the population served, and more than half completed as regards the expense involved; that is, $2,528,574 has been expended to date, and the estimated cost of the sewers necessary to complete the system is $1,861,960.

(2) The Cuyahoga river is now badly polluted with city sewage, as well as with manufacturing wastes. This pollution will be largely removed when the intercepting sewer system is completed, and then the city can insist upon purification, at individual plants, of those manufacturing wastes which may continue to enter the river direct.

(3) There is definite evidence that the discharge of untreated sewage in the lake at the main outfall has proved objectionable from the standpoint of pollution of bathing beaches; and there is some evidence that such discharge of sewage may under present conditions contaminate the city water supply at the intake crib.

(4) Sewage purification works, adequate to protect the water supply from contamination from the main sewer outfall, would cost much more than works designed to simply clarify the sewage and to protect the bathing beaches. Sewage works even though producing a highly purified effluent, would not prevent possible pollution of the water supply from objectionable surface drainage entering the river and its tributaries within the city limits. Neither would such works protect the water supply from the diluted sewage which must pass into the lake once or twice a month through some thirty storm-water overflows in the sewer system.

(5) Any plan for sewage purification which may be adopted should provide for purifying 100 million gallons of sewage per day, representing the quantity produced by one million people.

(6) The city's sewage may be treated by one plant located near the southeasterly city limits; or, by two plants, each receiving about one-

half the output of the city, one at the above location, and the other in Cuyahoga river valley south of the city. The additional cost for sewers and for disposal works, if one-half the sewage is thus diverted toward the south, would not be great; and if it should be decided that filters were necessary in the northeasterly installation, then there would be a distinct saving by constructing the southerly plant.

(7) The cost of construction of the suggested sewage treatment plants, on the basis of one million people, eliminating untried methods, varies roughly from $1,100,000 to $7,700,000, according to the type of plant and degree of purification sought. The estimated yearly expenditure, including interest charges, varies roughly from $140,000 to $750,000.

(8) The probable minimum difference in annual cost, including interest charges, between a low-efficiency sewage plant (to be used in case water purification works are installed), and a high efficiency sewage plant (to be used in the absence of water purification works), is $104,000; this difference may be increased if it is shown by the detailed tests, recommended further on, that larger quantities of bleaching powder than those herewith estimated are necessary to effect satisfactory purification. The difference in annual cost between tank treatment alone and tank treatment together with coarse-grain filters is $160,000.

(9) In order that the problem may be viewed from the broadest standpoint the above figures after being verified or corrected by further study and tests should be compared with the estimated total annual expenditure necessary to purify the water. If the difference in annual charges for the two types of sewage plants equals the annual charges for a water purification plant, then, on the financial grounds alone the solution of the pure water problem would be the installation of a water purification plant, together with a sewage plant to remove the objectionable suspended matter, provision being made for disinfecting during the summer time the sewage thus clarified.

(10) Before definite conclusions can be drawn regarding the most economical plan for treating the sewage, there should be conducted during the period of about a year a series of actual tests and experiments on the various feasible methods.

Necessary equipment and facilities for making these tests could be readily installed near the present outfall sewer. The various features which should be investigated comprise in general the study of the character of the city sewage discharged at the main outfall, and also of the sewage discharged through the various main branches; a study of the most suitable design of tanks and filters for use under local conditions, a study of the possibility of drying sludge along the lake front without creating a nuisance; the feasibility of clarifying the sewage by fine screens alone without the use of tanks, and the determination of the amount necessary of bleaching powder to suitably disinfect the effluent

from the screening treatment, tank treatment, and filtration treatment, respectively.

In connection with these tests, it is also recommended that studies be made relative to the most economical method for purifying the water supply of Cleveland, in order that the cost involved in such water purification may be compared with accuracy to the difference in cost between the low efficiency and high efficiency sewage plants.

ROCHESTER, N. Y.

This city, with a population of 218,149 in 1910, is situated on the Genesee river some distance from Lake Ontario. In 1906–07 Mr. E. A. Fisher, City Engineer, with the aid of Mr. Emil Kuichling, prepared a project for the disposal of the sewage, after passing it through screens and grit chambers, into Lake Ontario, some 7000 feet from shore in a depth of about 45 feet of water. This project was endorsed by Messrs. Hering and Benzenberg in January, 1907.

When application was made to the State Department of Health for approval of the plans for the project, considerable discussion arose. The State called in as special advisors, Messrs. Allen Hazen, Consulting Engineer; X. H. Goodnough, Chief Engineer, Massachusetts State Board of Health; and F. Herbert Snow, Chief Engineer, Pennsylvania State Department of Health. The reports of these gentlemen with the recommendations of Mr. Theodore Horton, Chief Engineer of the New York State Department of Health, are reviewed at length in *Engineering News* of Aug. 11, 1910.

Briefly, it may be stated that all of the engineers above mentioned endorsed this method of sewage disposal for the city of Rochester and the few changes that were made or advised are of minor significance. However, it was advised by the State Department of Health that the capacity of the grit chambers or settling basins be doubled, or increased from about 24.5 minutes to 50 minutes as measured in terms of sewage flow. The size of the mesh of the screens approximately is 0.085 inch Storm-water overflows will continue to be discharged into the Genesee river. The nearest water works intake is about 3 miles west of the proposed submerged sewage outfall.

ERIE, PA.

Upon the advice of the author in 1910, the city of Erie, Pa., which is now building a system of intercepting sewers, proposes

to screen and pass its sewage through Imhoff tanks of a capacity of 40 minutes, average dry-weather flow, and then disperse the effluent in Lake Erie through multiple outlets in 26 feet of water and about 4000 feet from shore. The storm overflows will be discharged into Mill creek and along the harbor front. Mr. B. E. Briggs, City Engineer, has studied the question carefully, especially as to currents as shown by float tests. On the opposite side of a peninsula is the water works intake, distant about 5 miles. The city had a population of 66,525 in 1910.

It is proposed to apply hypochlorite treatment to the sewage effluent when required for further safety. But it is the opinion of the author that it is unnecessary to sterilize the clarified sewage here except at times of epidemics, as it is the regular practice to provide this treatment for the water supply since the typhoid epidemic of 1910–11. The State Department of Health before final approval of this project has recommended that certain tests be made pending the installation of the intercepting sewers.

OSWEGO, N. Y.

Most of the existing sewers of Oswego, with a population of 23,368 in 1910, now discharge into the Oswego river and more or less pollute the harbor. A new water supply is approaching completion. It is drawn from Lake Ontario from a depth of about 75 feet, and about 8000 feet from shore in accordance with recommendations of the author.

On the west side of the city where new sewers are soon to be built, Messrs. Hering & Fuller recommended in 1911 the installation of Imhoff tanks in conjunction with hypochlorite treatment, the effluent to be discharged into the harbor near the opposite end from the main opening in the break water which surrounds the harbor.

MILWAUKEE, WIS.

Improved conditions for securing the most proper solution of the questions of water supply and sewage disposal were reported upon in 1889 by a special commission, composed of Messrs. G. H. Benzenberg, Thomas J. Whitman, Joseph P. Davis, and Henry Flad. They recommended an intake in deep water off North Point and the dispersion of the sewage through multiple outlets into deep water of the lake to the southeast of the city.

Their views as to multiple outlets are illustrated by Fig. 9 and are described in their report as follows:

Recommendations of 1889.—At the lake end of the outfall sewer a terminal basin is to be built. From this basin two iron pipes, each 56 inches in diameter, are to discharge the sewage into the lake.

These pipes are to be of sufficient capacity to carry all of the dry weather sewage, and a portion of the storm water. The basin is to be so arranged that the surplus of storm water is discharged over a weir, directly into the lake.

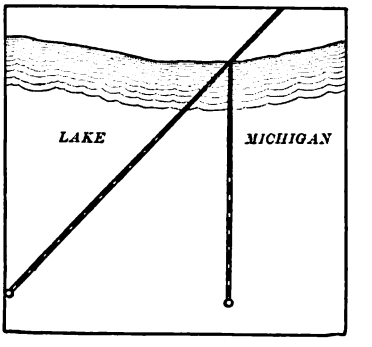


FIG. 9.—Multiple sewage outlets.

At times it may be necessary to increase the velocity of flow through the discharge pipes, in order to remove sediment. When this is the case the space above the weir is to be closed by means of stop planks or gates, so that the surplus water delivered through the outfall sewer at the time of a heavy rain (or by the use of additional pumps) will raise the level of the water in the terminal chamber sufficiently to produce the desired velocity.

One of the 56-inch pipes is to be laid at right-angles with the shore, from the point where the terminal basin is built, and to be about 6000 feet in length; the other pipe is to be on a line running to the southeast, and to be about 8000 feet in length. The outer ends of the pipes will be in water about 30 feet in depth and are to about 5000 feet apart.

In order to dilute the sewage to a high degree in the shortest possible time, and thus promote the rapid oxidation of the organic matter contained in it, the discharge from the 56-inch pipe is to be through 11 branch connections, placed about 300 feet apart; the first discharge branch being placed about 3000 feet from shore. The branches are to be 17 inches in diameter, and reduced, at the points of discharge, so that the same quantity of sewage will be delivered by each branch. The size of the main pipes is to be diminished, after passing each branch, so that the velocity of flow may be maintained about the same throughout the entire length.

The branches are to be placed in a vertical position, discharging about 5 feet above the bottom of the lake, and to be secured in their position by piles, or rip-rap filling.

For a distance of 1000 feet from its outer end, the main pipe is to be laid on piles, so as to bring the discharge about 6 feet above the bottom of the lake. Any road detritus or other material that may at long intervals accumulate at the mouth of the pipe, can be removed by dredging.

In speaking of the Milwaukee sewage problems, it should not be forgotten that the Milwaukee river itself in earlier years was a foul stream owing to excessive pollution from sewage and sewage deposits. Those conditions were successfully removed by a flushing tunnel designed and built by Mr. Benzenberg, then City Engineer, and put in operation in September, 1888. Through this tunnel about 680 cubic feet per second of lake water are said to be discharged in the upper portions of the polluted section of the river, thereby eliminating the nuisances.

Report of 1911.—In 1911 Messrs. John W. Alvord, Harrison P. Eddy and George C. Whipple made a comprehensive report on the sewage question at Milwaukee, not only with respect to eliminating the existing nuisance along Menominee creek, but also in relation to the unfiltered city water supply which is drawn from Lake Michigan at a distance of about 4 miles northeast of the river mouth and 8200 feet from shore at a depth of about 60 feet.

The report has made the impression on some engineers of being somewhat radical in its recommendations unless as stated a considerable term of years is required for execution. With the latter thought in mind, the recommendations are more in line with developments at other lake cities. In studying the cost of the recommended works it should be borne in mind that the population of Milwaukee in 1910 was 373,857.

This report is understood to be very complete in its various details, but unfortunately it has not yet been published. A summary is quoted in part from the *Engineering Record* of May 20, 1911, as follows:

General Recommendations.—The findings outlined above led to the following recommendations: A water filtration plant, construction to be begun immediately; flushing works for the Menominee river to be begun at an early date and completed by 1915; a high and low-level intercepting sewer system, together with the necessary pumping equipment, to divert sewage from the rivers and convey it to purification works, so as to restore the rivers to a condition of reasonable cleanliness. The method of sewage treatment recommended for the present comprises clarification in suitable sedimentation tanks and disinfection. Provision has been made for percolating filters when further purification of the sewage, in the future, will demand this form of treatment.

The estimated cost of all works recommended for immediate construction, to be completed prior to 1915, is $4,997,000; the estimated cost of all works recommended for completion prior to 1950, is $13,255,000.

Recommendations for Sewage Disposal.—The sewage collected by the high-level interceptor will reach the disposal works site, an area of 26 acres on the Kinnickinnic river, near the existing flushing works pumping station, by gravity. The low-level flow, however, will be lifted against a maximum head of about 42 feet into the sedimentation tanks by a new pumping station to be built at the purification works. The sewerage systems will be built by degrees as the need for them arises. The site on the Kinnickinnic river selected for the sewage purification works is large enough to accommodate only such works as are required for a partial purification of the flow. The works recommended consist of 5 grit chambers, screens, 30 baffled sedimentation tanks for removing the suspended matters and a disinfecting station. There will also be sludge tanks and a sludge steamer or barges for carrying sludge out into the lake. The works are intended to have a capacity sufficient for the quantity of sewage estimated for the year 1930 or 100,000,000 gallons daily. At that time it is expected that by the addition of 3 grit chambers and 15 sedimentation tanks the capacity of the plant will be sufficient until 1950.

The sedimentation tanks suggested in the report will measure 160 x 40 feet in plan, with a depth of 9 feet at the inlet end and 7 feet at the outlet end. The tanks are to be covered by concrete groined arch vaulting. Construction of the tanks probably will not start immediately, so that if the results of operation, on a large scale, of other forms of tanks, such as those of the Imhoff type, indicate their superiority over the ones suggested in the report a change can then be made.

If all of the sewage could at all times be passed through the purification works the commission of engineers would not hesitate to advise the constant use of a disinfectant, such as hypochlorite of lime, for the purpose of reducing to a minimum the number of pathogenic germs discharged into the lake. At Milwaukee, however, it is not practicable to collect all of the sewage, especially in time of storm, so that the advisability of disinfecting the effluent is somewhat questionable. If it appears that the effluent from the purification works may at times cause an infection so great that the filtration of the water supply cannot be safely relied upon to correct it then the partially or even the more completely purified sewage effluent should be disinfected. In view of all circumstances the commission believes it wise to provide for a suitable disinfecting station at the Kinnickinnic purification works and later at the works for more complete purification, when installed. The details of the plan for disinfection will be left to the future.

The works provide for a more complete purification of the sewage than can be obtained with the screens and tanks and will require about 60 acres of land, which will be made available by filling in an area on the lake shore at South Point. They will comprise percolating filters of broken stone about 7 feet deep and final sedimentation tanks. Messrs.

Whipple and Eddy do not feel that at the present time it is feasible to fix a date when such works will be necessary, but suggest the plant as a practicable means of carrying the process of sewage purification to greater completion whenever conditions shall indicate that it is necessary. The building of percolating filters, they believe, may be deferred for many years. Mr. Alvord, however, feels that the percolating filters should be built at the same time the outfall sewer is constructed to prevent tank effluent, even though disinfected, from being emptied into the lake in the quantities considered at Milwaukee.

ITHACA, N. Y.

In 1896 this city of about 13,000 population completed the installation of a sewerage system, the flow of which was disposed of by pumping through a wooden outfall pipe extending about 7000 feet into Lake Cayuga. It is understood that no difficulty from odors was experienced in the lake around the point of dispersion.

As the city increased in size it was found necessary to supplement the original installation. In accordance with the advice of Messrs. Williams and Whitman it was decided to install a septic tank and to deliver the sewage through a shorter outfall extending some 1000 feet on land and 300 feet into the water of the "inlet." These works were put in service in 1908. Their construction was supervised by Prof. H. N. Ogden, who states that no difficulties have been experienced except as to odors from the septic tanks at the beginning. These odors were eliminated almost completely by covering the tanks. The outlet is in 6 feet of water about 100 feet from the shore. Prof. Ogden describes the effect upon the inlet water of the sewage after clarification in septic tanks, as follows: No evidence of the sewage discharge is visible in the inlet, but complaints have been made by boatmen of the rapidly increasing deposits in the vicinity of the outfall pipe. During the ten years that the sewage, about two million gallons a day, discharged into the lake, no evidence whatever of such discharge was perceptible.

MADISON, WIS.

The city of Madison, Wis., installed sewerage works in 1886, discharging the crude sewage into lakes Mendota and Monona, the areas of which are 15 and 6 square miles, respectively. With

the increase in sewer connections complaints regarding the pollution of the lake grew more numerous. In 1893 efforts were begun to abate the nuisance through the installation of treatment works. Available records do not show how far effort was made to disperse the sewage in the lake, but from the location of the disposal works and other collateral information, it is not likely that the dilution method which failed there was representative of the modern type of dispersion. In *Engineering News* of Feb. 15, 1912, Mr. James Mackin describes a new local project for sewage purification.

CHAPTER X

DILUTION IN OCEANS AND TIDAL ESTUARIES

The disposal of sewage is oceans or in adjoining bays, harbors or tidal estuaries brings into account the questions of tides and of the salinity of the diluting water, which in turn are related to a number of new or different factors as compared with the fresh water encountered in inland streams and lakes, as follows:

1. Differences in specific gravity due to mineral contents tend to modify and, if great enough, to reduce the ease of mixing the fresh water sewage with the denser salt or brackish water, unless the initial velocity and the location and manner of entrance of the sewage are arranged especially to promote mixing. The tendency within certain limits as to velocities and volumes is for the lighter sewage to form a surface stratum upon the heavier sea water.

2. Differences in temperature also cause differences in specific gravity and tend somewhat to retard mixing under certain circumstances, due to a likelihood of the warmer sewage forming a surface stratum upon the colder and denser sea water, unless specially controlled as to the conditions of entrance of the sewage.

3. While the mixing of sewage with salt water is influenced somewhat by differences in salinity and temperature, particularly in docks and small arms or bays, and where the entering velocity is not checked, it is not to be forgotten that winds and tides are strongly conducive to general dispersion; and furthermore that the completeness of mixing within certain limits is promoted by diffusion, convection currents and vortexual motions more in salt than in fresh water.

4. A smaller coefficient for the absorption of atmospheric oxygen is found in sea water at corresponding temperatures and pressures than in fresh water.

5. There are differences in the reaeration of sea water as compared with fresh water, due to the oxygen absorbed at the surface diffusing downward under the influence of factors not fully understood.

6. The marked increase in mineral content of the sea water

may assert itself in ways not fully understood. Mention may be made of the reduction of sulphates and the liberation of hydrogen sulphide.

7. The tendency for salt water is to precipitate or coalesce more colloidal or dissolved matters of sewage than is the case in fresh water.

8. The development of a distinctive flora of bacteria and grosser organisms, including certain types of "seaweed" may in themselves give offensive decomposition odors if stranded upon the shore.

9. Rapidly changing water levels due to the action of the tides, cause in some instances an exposure at low tide of mud-covered flats.

10. Sewage muds in salt or brackish water seem to be larger in quantity, to decompose more quickly and completely, and to make more of a tax upon the dissolved oxygen of the overlying water than in the case of fresh water.

11. Complications occur in the direction and intensity of currents due to the influence of tides when coupled with the effect of winds and an "underrun" of salt water. Four times daily the tide turns and there is a reversal of the general direction of flow. In fairly deep water the tide does not turn at the same time at the surface and bottom of the water. In other words, in the same vertical plane transverse to the main current there is always some velocity of flow.

12. While velocities of flow, usually determined by floats, over the point and area of dispersion are highly important in ocean disposal as well as in lakes, it is necessary in tidal estuaries to study the replenishment of the diluting water. Ordinarily this comes in part from the land water and in part from clean salt water direct from the ocean. It usually involves a calculation of the "tidal prism" equal to the area of the body of water in question multiplied by the rise of the tide. Then by the "piston method" there is computed for the given conditions the approximate frequency with which the body of polluted water is displaced by clean water. The question is a complicated one and special study is required for each problem.

13. A proper consideration is required for shellfish layings with regard to the control of the disease germs in sewage, as explained at length in Chapter V.

At present most of the states and cities along the northern

Atlantic seaboard are taking steps more or less actively to secure practical protection of shellfish against pollution. Several large cities and many small places are striving for a greater purity of harbor waters. Particularly is this true in and around New York City.

Rather than to discuss seriatim the points wherein salt water disposal differs from that in fresh water, as discussed in Chapters VIII and IX, at a time when these matters are being litigated by the states of New York and New Jersey, we shall outline some of the more important experiences and reports. Incidentally mention will be made of some observations bearing upon the differences set forth above.

AMERICAN EXPERIENCES WITH THE DISPOSAL OF SEWAGE IN SALT WATER. BOSTON HARBOR

In 1875 the water front of Boston harbor and neighboring waters began to show seriously offensive conditions as a result of the discharge of sewage.

Commission of 1875.—The Mayor of Boston appointed a commission composed of Messrs. E. S. Chesbrough, C. E., Moses Lane, C. E., and Chas. F. Folsom, M. D., whose conclusions were as follows:

The point which *must* be attended to, if we would get increased comforts and luxuries in our houses, without doing so at cost of health and life, is to get our refuse out of the way, far beyond any possibility of harm, before it becomes dangerous from putrefaction. In the heat of summer this time should not exceed twelve hours. We fail to do this now in three ways:

(1) We cannot get our refuse always from our house drains to our sewers, because the latter may not only be full themselves at high tide, but they may even force the sewage up our drains into our houses.

(2) We do not empty our sewers promptly, because the tide or tide gates prevent it. In such cases the sewage becomes stagnant, a precipitate falls to the bottom, which the slow and gradual emptying of the sewers, as the tide falls, does not produce scour enough to remove. This deposit remains with little change in some places for many months.

(3) With our refuse, which is of an especially foul character, once at the outlets of the sewers, it is again delayed, there to decompose and contaminate the air.

As a result of this failure to carry out the cardinal rule of sewerage, we are obliged to neglect the second rule, which is nearly as important, namely, ventilation of the sewers; for the gases are often so foul that we

cannot allow them to escape without causing a nuisance; and we compromise the matter by closing all the vents that we can, with the certainty of poisioning the air of our houses.

In the opinion of the commission there are only two ways open to us. The first, raising more than one-half of the superficial area of the city proper (excluding suburbs), is entirely out of the question, from the enormous outlay of money which would be required—more than four times as much as would be needed for the plan which we propose, and which consists in intercepting sewers and pumping.

There are in use now in various parts of the world three methods of disposing of the sewage of large cities, where the water-carriage system is in use:

(1) Precipitation of the solid parts, with a view to utilizing them as manure, and to purifying the streams.

(2) Irrigation.

Neither of these processes has proved remunerative, and the former only *clarifies* the sewage *without purifying it;* but if the time comes when, by the advance in our knowledge of agricultural chemistry, sewage can be profitably used as a fertilizer, or if it should now be deemed best to utilize it, in spite of a pecuniary loss, it is thought that the point to which we propose carrying it will be as suitable as any which can be found near enough to the city, and at the same time far enough away from it.

(3) The third way is that adopted the world over by large cities near deep water, and consists in carrying the sewage out so far that its point of discharge will be remote from dwellings, and beyond the possibility of doing harm. It is the plan which your commission recommends for Boston.

Moon Island Outlet.—From storage reservoirs built by the Boston Main Drainage works on Moon island sewage is discharged practically at the surface of the water during the second and third hours after the tide has turned and flows to the ocean. In 1899 it became necessary to build additional reservoirs at Moon island to provide facilities for the rapidly increasing volume of sewage there discharged. (See *Engineering Record*, Nov. 4, 1899.) A sketch showing the location of the present outlets in Boston harbor and vicinity is given in Fig. 10.

Deer Island Outlet.—With the establishment in 1889 of the Metropolitan Sewerage District, the sewage of the towns lying north of the Charles river, upon the recommendation of the State Board of Health, was diverted to a new harbor outlet at what is known as Deer island. This was put in service in 1895. A description of the works is given in the *Engineering*

Record of Feb. 9 and May 11, 1895. The discharge of sewage is continuous through an outlet in fairly shallow water.

Peddock's Island Outlet.—Further relief was obtained in 1904 with a third outlet spoken of as the Peddock's island or Nut island outfall. Sewage there is discharged continuously through two 60-inch cast-iron pipes with mouths looking upward. The

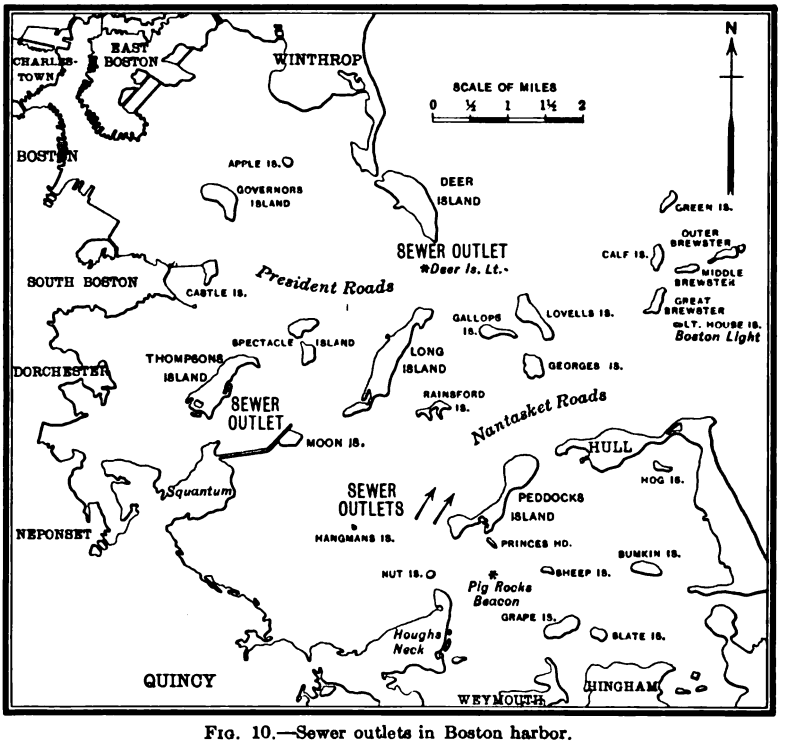


FIG. 10.—Sewer outlets in Boston harbor.

outlets are in about 30 feet of water, as described in the *Engineering Record* of Aug. 15, 1903, and are in accordance with the advice of the State Board of Health.

Varying Viewpoints.—More or less difference of opinion has prevailed as to the adequacy of the disposal of the Boston sewage. To some the results appear quite unsatisfactory owing to the visible sewage "field" characterized by more or less sleek and discoloration in the general vicinity of the outlets. To others the present results, considered with the successive improvements which have been and can be still taken, cause the method to be

considered reasonably satisfactory. Particularly is this so when compared with the cost and probable fault-finding that would attend any purification works that could be carried out. A paper by Profs. Winslow and Phelps with a discussion by Prof. Sedgwick, affords considerable food for reflection, however, on this question. It was presented to the Boston Society of Civil Engineers in November, 1907, and appears in the *Journal of the Association of Engineering Societies*, Vol. XL, page 40. It contains the results of important purification tests supplementary to those printed as Water Supply and Irrigation Paper No. 185 of the United States Geological Survey.

Special Investigations.—The Massachusetts State Board of Health and also the Metropolitan Water and Sewerage Board have given this question much careful study. The State Board of Health has likewise investigated the discharge of sewage from various other centers of population along the Massachusetts coast. The detailed reports should be consulted by those desiring to make a careful study of the subject.

Summary of 1902.—The main features developed in the investigations in 1901 and 1902 are well shown in the summary of the State Board of Health given on page 307 of their report for the year 1902, as follows:

> The objectionable conditions caused by sewer outlets may be divided into two classes: (1) cases in which the quantity of sewage is so great in proportion to the quantity of water with which it is mingled that the water is rendered offensive; and (2) those in which the objectionable conditions are caused by faulty construction or location of the outlet itself.
>
> The objectionable conditions caused by the discharge of an excessive quantity of sewage into a body of water are few among those outlets which discharge into the sea.
>
> At Moon island, where the quantity of sewage discharged is rapidly approaching the capacity of the works for conveying it to the outlet and the capacity of the tidal currents into which it is discharged, the sea water for a distance of a mile or more from the outlet is rendered offensive by the sewage for about two hours after each discharge, but the sewage quickly disappears after the discharge ceases. Upon the completion of the high-level sewer, now under construction much of the sewage discharged at this outlet will be conveyed to the new outlet at Peddock's island.
>
> At Salem the water of the North river, into which a great quantity of sewage and manufacturing wastes is discharged, is rendered extremely

offensive; but the effect of the pollution disappears rapidly in the tidal estuary into which the stream flows, so that the water in the lower part of the estuary is not noticeably objectionable, but the flats in this estuary are very offensive when exposed.

Similarly, at New Bedford the water of Acushnet river near its entrance to the harbor is greatly polluted by the sewer outlets; but, except near the New Bedford shore, the harbor water is not noticeably objectionable. In Clark's cove also the effect on the water of the cove is confined to the extreme upper end.

Of outlets which are objectionable on account of construction or location of the outlet there is a very large number.

The results of the examinations of sewer outlets into the sea or harbors or other arms of the sea show in general that when the outlets are located in deep water, where they are submerged at all times, noticeable deposits of sewage rarely take place; and an odor from the sewage is rarely noticeable at any considerable distance from the outlet, even in cases where the movement of the water is slow provided the water is changed regularly by the movement of the tides. Where outlets discharge into considerable tidal currents well away from shores or from flats exposed at low water, the sewage is quickly removed and dispersed, and evidences of it do not accumulate about the outlet.

Among the outlets where objectionable conditions have not been found may be mentioned the outlet of the north metropolitan sewerage system at Deer island, which has now been in use for eight years, where from 2,000,000 to 3,000,000 gallons of sewage are discharged each hour at the present time at all stages of the tide. The outlet is off the end of a sand spit exposed at low water and distant 1800 feet from the nearest shore at high water. No deposits have yet taken place upon any of the shores near this outlet, and there is no evidence that deposits are accumulating anywhere. The sewage can be seen upon the surface of the sea water in calm weather for a distance of less than a mile from the outlet, and the oily matters from the sewage which float in a very thin film on the surface of the water may be detected at a somewhat greater distance, but an odor from the sewage is noticeable only to those sailing in the stream of sewage in the immediate neighborhood of the outlet itself.

There are cases where sewage is discharged below the level of low water, but in such a way that the sewage collects about the outlet, and causes offensive conditions. This is the case especially where sewage is discharged into docks between long wharves or into small bays or arms of the sea, where the sea water is not frequently changed by the movement of the tides, and the sewage consequently receives too little dilution.

At the outlets of sewers which discharge at the edge of low water on a beach or flats, under conditions where there is little or no current, the

sewage collects in the water, rendering it offensive to sight and smell, and deposits of offensive matters accumulate. At such outlets matters from the sewage are gradually spread over the beach or flats by the tide, where they remain and cause offensive odors when the shores are exposed.

All of the outlets discharging upon beaches or flats between low water and high water have been found to be objectionable, because there is an offensive odor both from the sewage itself and from the decomposition of sewage deposits which take place about such outlets.

In several cases sewage is discharged into open trenches, even above the level of high water, and all of such outlets examined have been found to be very offensive.

Summary of 1905.—In the report of the Massachusetts State Board of Health, 1905, pages 413–57, is given a record of results of conditions and analyses of samples of Boston harbor water, with especial reference to shellfish pollution. A statement of some of the findings is to be found in Chapter V, page 151. The sanitary conditions in general are described by the Board as follows:

The examinations of sewer outlets during the year 1905 have been confined chiefly to investigations of the effect of the discharge of sewage into Boston harbor. Observations have been made during the year of the effect of the discharge of sewage from the three principal sewer outlets into the harbor—those of the Boston main drainage system at Moon island and the north and south metropolitan sewer systems at Deer island and Peddock's island, respectively. In connection with these observations, numerous chemical and bacterial analyses have been made of the waters in all parts of the harbor as well as in the portions affected by the discharge of sewage from the main sewer outlets.

In addition to the discharge of sewage at the main outlets, a large quantity of sewage overflows at times of rain from the combined sewer systems in Boston, Cambridge, Somerville and Chelsea into the waters of the upper harbor and the estuary of Charles river, and to a smaller extent into Mystic and Neponset rivers. A considerable quantity of sewage is discharged directly into the harbor or its tributaries at all times from a few sewers not connected with the metropolitan system, chiefly in Chelsea. A large part of the sewage of the city of Chelsea is discharged directly into the harbor instead of into the metropolitan sewerage system, which was designed to receive it, the reason being, apparently, the neglect of the Chelsea authorities to maintain their sewers in such condition that the sewage can reasonably be admitted to the metropolitan sewerage system. Besides the sewage from these outlets and from the storm overflows, the harbor receives a considerable quantity of direct pollution by sewage from buildings and wharves along

the harbor fronts of the cities and from vessels, and a small quantity of sewage is discharged from institutions on the islands.

The odor from the Moon island outlet is offensive for a distance of half a mile from the outlet under ordinary conditions, and is noticeable at times at greater distances. At Deer island an odor is rarely noticeable at a distance of more than a quarter of a mile, while at Peddock's island an odor is observable at the present time only immediately about the outlet.

Chemical examinations of the harbor water in the region affected by the discharge of sewage at the Moon island outlet and of the harbor water at other points in this neighborhood during the past summer have shown that the sewage does not spread materially outside of the area in which it is visible by inspection. Some effect of the sewage is nearly always noticeable, by chemical and bacterial analysis, in the area over which the Moon island sewage flows twice daily. In the vicinity of the outlet and along the sea wall extending about 1500 feet southeasterly therefrom, deposits collect in summer, and when the wind is off shore combine with the effect of an eddy, to retain some noticeable effect of the sewage in this region.

At Deer island chemical analyses show that the sewage is confined to the narrow field in which it is ordinarily visible on the incoming tide. On the outgoing tide the sewage from this outlet flows directly to sea.

Chemical and bacterial examinations of samples of the water from all parts of Boston harbor, both on the incoming and outgoing tide, and from points outside the harbor, show that, while the sea water from outside the harbor is low in bacteria and free from B. coli, the characteristic organism of sewage, nearly all of the samples collected inside the harbor, on the other hand, contain comparatively large numbers of bacteria, and in all but two samples out of more than 100 in this series the colon bacillus was found to be present.

The chemical analyses show, in general, results similar to the bacterial analyses, the water of all parts of the harbor containing a higher free ammonia than is found in water from outside of the harbor. The least evidence of pollution was found in Hingham bay, where the free ammonia and the bacteria present were lowest; while the greatest pollution was found in the waters of the inner harbor, *i.e.*, in the portion of the harbor between Governor's island and the mouths of the Charles and Mystic rivers.

Careful examinations of the shores of the harbor show that they are in general affected but slightly by the presence of matters discharged from the main sewer outlets. The only matters found upon the shores which could be identified as probably derived from sewer outlets were grease balls and particles of grease. The grease balls are formed in the sewers around pieces of cork, matches or other floating objects, and these and

the light particles of similar greasy matter float upon the water and are carried for long distances from the sewer outlets. This matter is found on the islands and the shores in all parts of the harbor excepting in the southerly part of Hingham bay, and is found to some extent along the outer shores outside of the harbor entrance. The quantity at all places is very small, and in most places it can be detected among the seaweed and other debris along the shores only by a most careful inspection.

The results of the examinations of the sewer outlets and the effect of sewage disposal in Boston harbor show that the waters of all parts of the harbor are affected to some extent by pollutions from the sewers and by the other wastes from the great population about it.

The most seriously polluted portion of the harbor at the present time is the inner harbor inside of Governor's island. The pollution of this portion of the harbor is caused in part by the discharge of sewage from buildings and wharves on the harbor front, which might be connected with the local sewers, and in a large part by the direct discharge of sewage from sewers in Chelsea, East Boston and some other places.

Summary of 1907.—In 1907 the State Legislature of Massachusetts directed the State Board of Health to report in the following January "as to the best means of preventing further pollution of Boston harbor by the discharge of foul sewage at Moon island." The Board stated their findings on page 7 of their report for 1907, as follows:

The sewage discharged at the Moon island outlet is that which is collected by the main drainage system of the city of Boston. In character it is not essentially different from that of other cities, except for a slight admixture of salt water which leaks into the sewers located near the shores of the harbor and its estuaries, through tide gates and in other ways. It becomes somewhat decomposed in its passage through the deposit sewers, the tunnel, and especially the reservoirs at Moon island, in which it is stored for several hours in order to admit of its discharge only in the second and third hours of the outgoing tide, when the currents are most favorable for its speedy removal and dilution with a large volume of sea water; but at the time of its discharge it is not noticeably more offensive than the sewage of other cities and towns stored in reservoirs for convenience in disposal.

The Boston main drainage works were completed and the outlet at Moon island first used in 1884. The quantity of sewage discharged there gradually increased for many years, owing to the growth of the city and the extension of sewers into metropolitan areas adjacent thereto, chiefly in the Charles and Neponset river valleys. The quantity of sewage delivered at Moon island eventually became so great that the reservoir capacity became unequal to the storage of all of the sewage for a sufficient length of time to allow for its discharge in the two most

favorable hours of the outgoing tide; but in 1899 the capacity of the reservoirs was doubled, and the necessity for discharging considerable quantities of sewage at unfavorable times was removed. In 1904 the quantity of sewage delivered at this outlet was greatly reduced by the completion of the high-level sewer and the diversion of all of the sewage of the Charles and Neponset river valleys into the high-level system, which has a separate outlet at Peddock's island. In subsequent years the sewage of other considerable areas has been connected with the high-level system, and, while no satisfactory records of the quantity of sewage discharged at Moon island are available, the quantity discharged at Peddock's island—all of which has been diverted from the Moon island outlet within the past three years—amounted during the year 1906 to 33,600,000 gallons per day. It is probable that the quantity of sewage discharged at Moon island at the present time is considerably less than 100,000,000 gallons per day.

In the summer of 1905, after the quantity of sewage discharged at Moon island had been reduced by the diversion of the sewage of the Charles and Neponset river valleys into the high-level system, an investigation was made by this board to determine the condition of the water of Boston harbor and the effect of the discharge of sewage therein. This investigation showed that the quantity of free ammonia present in the waters of the inner harbor —*i.e.*, inside or west of a line drawn from the easterly end of East Boston to South Boston—was greater on the outgoing tide than anywhere in the region of the harbor about Moon island, excepting in the narrow path taken by the sewage in passing from Moon island to the sea and within two and one-half miles of Moon island. On the incoming tide the quantity of free ammonia found in the water of the inner harbor was greater than was found anywhere in the region about Moon island, excepting immediately about the sewer outlet itself.

The same is true of the results of bacterial examinations. On the outgoing tide the number of bacteria was higher in the inner harbor than anywhere about Moon island, excepting in the immediate track of the sewage and within two and one-half miles of the outlet. On the incoming tide the number of bacteria was greater in the inner harbor than anywhere in the neighborhood of Moon island, excepting immediately about the outlet.

Other examinations were made to determine more definitely the area affected by the discharge of sewage at the Moon island outlet, and samples of water were collected for analysis from numerous stations for a long distance about this outlet. The results confirm those of the previous investigations, showing that the effect of the sewage discharged at the Moon island outlet upon the harbor water is markedly noticeable only in a restricted area extending from the outlet along the path taken

by the sewage toward the sea, and that outside of this area, which at its greatest extension does not exceed two and one-half miles in length by one-half to three-quarters of a mile in width, and then only during the outgoing tide—the period when the sewage is discharged—is the water noticeably more polluted, as shown by chemical or bacterial analysis, than the water in the inner harbor.

An examination of the outlet at Moon island in August, 1907, and observations of the discharge of sewage there, indicate that the works at that point are well cared for, and the times of discharge strictly adhered to by the officer in charge of that work.

While the order of the Legislature does not appear to have been intended to include the main sewer outlets at Deer island and at Peddock's island, the Board would add that the sewage from those outlets—which is discharged in smaller quantities and also continuously at all stages of the tide, and hence in a very much smaller volume than at Moon island—has a much less noticeable effect upon the harbor water than that discharged at Moon island during the few hours immediately after it is discharged there.

In view of the fact that the waters of the inner harbor of Boston show more evidence of pollution than the waters of the outer harbor, excepting in the neighborhood of the main sewer outlets and in the immediate track of the sewage from Moon island after it has been discharged and is on its way to sea, and in view of the results of observations of the Board showing that the pollution of the inner harbor is not due to the discharge of sewage at Moon island or at either of the other main outlets, the Board sees no present necessity for the adoption of means for the prevention of the further pollution of the harbor by the discharge of sewage at Moon island or at either of the other main outlets.

Résumé.—The Boston data show conclusively the need of proper dispersion of sewage in an adequate volume of water. The submerged outlets at Peddock's island in a depth of about 30 feet are much preferable to the shallow discharge of fresh sewage at Deer island and much more preferable than the surface discharge at Moon island of sewage undergoing more or less decomposition in storage reservoirs and in conduits en route thereto. So far as known no study has been given at Boston to the question of multiple outlets arranged to avoid a concentration of sewage flow at a single point. It is interesting to note, furthermore, that at the Peddock's island outlets no especial effort was made to disperse the sewage near the bottom. Indeed the velocity of the discharge brings the sewage up to the surface from the vertical outlets.

In the report of the Metropolitan Water and Sewerage Board

for the year 1910, it is noted on page 66 that the large amount of sewage carried into the harbor through the Deer island outlet has caused the Board to make various inquiries which were considered desirable before improving in the future the method of discharge of the sewage from the North Metropolitan system.

Other seaboard cities of Massachusetts are giving this matter serious attention, particularly New Bedford, Lynn, Salem, etc.

PROVIDENCE HARBOR

It was not long after offensive conditions arose at Boston that similar results were noted in the upper reaches of Providence harbor in what is spoken of locally as the "cove." This resulted in careful investigations of disposal methods both in this country and abroad by Mr. S. M. Gray, at that time City Engineer of Providence. The first project in this country comprising chemical precipitation works was recommended by Mr. Gray in 1886. This method was much in vogue at that time in Europe, particularly in England. For the Providence problem it was endorsed in December, 1886, by a commission appointed through the American Society of Civil Engineers and composed of Messrs. Joseph P. Davis, Rudolph Hering and Robert Moore.

Extensive changes in the collecting systems of sewers were incidental to the conveyance of the Providence sewage to the chemical precipitation plant at Field's point. This plant is described in *Engineering Record* of May 4, 1901, *Municipal Journal and Engineer* of December, 1901, and is outlined in Chapter XV.

Prospective Sterilization.—Recently attention has been directed to whether the effluent from this plant discharged off Field's point in a depth of 36 feet of water is seriously prejudicial to certain shellfish layings. It is understood that for some time experiments have been made with the hypochlorite treatment for the purpose of destroying objectionable bacteria and allowing the lower harbor waters to meet the standards of purity set up by the U. S. Pure Food Board. The outcome of this will be awaited with much interest by sanitarians.

FIRST STERILIZATION PLANT AT RED BANK, N. J.

In passing it may be mentioned that since October, 1906, the sewage of Red Bank, N. J., has at intervals been subjected to the hypochlorite treatment in conjunction with a single-story

septic tank. The purpose was to protect shellfish. This important advance in the art of sewage treatment was largely due to Prof. E. B. Phelps, who describes the process in United States Water Supply and Irrigation Paper No 229.

In December, 1910, Messrs. Hering & Fuller recommended hypochlorite treatment for the sewage of New Brunswick, N. J., to be used at two sewers outlets in conjunction with fine screens and at a third outlet in conjunction with Imhoff tanks. This was done in conformity with the orders of the New Jersey State Board of Health to protect the shellfish of Raritan bay.

In conformity with the requirements of the New Jersey State Board of Health a number of other projects have been developed largely with a view to protecting shellfish layings.

BALTIMORE, MD.

In 1893 the first Sewerage Commission of Baltimore was appointed to consider the installation of a modern sewerage system as well as the disposal of the sewage. This Commission made a report in 1897, recommending that the sewage, after some sedimentation be disposed of by dilution in Chesapeake bay. This conclusion was concurred in by the late Gen. William P. Craighill, former Chief of Engineers, United States Army. The consulting engineers, Messrs. S. M. Gray and Rudolph Hering, recommended the more expensive method of intermittent sand filtration.

The question of pollution of the extensive oyster layings in the bay was considered somewhat in the report above mentioned. But the city officials were apprehensive on this score and directed the commission to prepare an alternate plan which would relieve public apprehension as to oyster pollution.

The second report was made in 1899. In it consideration was given to recent developments abroad in biological methods of sewage disposal. The Commission did not modify its views as to the dilution method being the best for local conditions, but recommended as the best alternative plan sand filtration in Anne Arundel County. The decision between the two methods was to be determined by such referendum procedure as the Mayor and Council might select.

The matter remained in abeyance until 1905, when a new enabling act was passed by the legislature. It created the present or second Sewerage Commission of Baltimore and made it mandatory that the sewage be purified. The act

gave no authority for the construction of a system involving the discharge of raw sewage as distinguished from storm water or ground drainage into the Chesapeake bay or any of its tributaries.

The first installation of purification works, under the direction of Mr. Calvin W. Hendrick, Chief Engineer, is now practically completed and ready for service. They consist of sedimentation tanks, rotary screens of fine mesh, sprinkling filters, and final settling tanks. These works are in general conformity with the recommendations of Messrs. Hering, Stearns and Gray in 1906, as set forth in the *Engineering Record* of July 28, 1906, and *Engineering News* of Aug. 16, 1906. They are described in detail in the *Engineering Record* of Feb. 27, Nov. 13, 1909, and Feb. 24, 1912.

The hypochlorite treatment had not passed beyond the experimental stage in 1906, and final sand filtration was considered by the Board of Advisory Engineers. Later it was decided to omit the sand filters and to adopt the hypochlorite treatment if need be. It is understood that it is not expected to sterilize the effluent, at least at the outset, when the filtering area will amply take care of the comparatively small sewage flow during the next few years. The effluent will discharge into Back river, some 14 miles from the point in Chesapeake bay where shellfish layings are really cultivated.

CHARLES RIVER BASIN IN MASSACHUSETTS

The tidal basin of the Charles river extends from the dam at Watertown to the upper Boston harbor, a distance of nearly ten miles. It separates for a part of its length the cities of Boston and Cambridge, and on its shores are located on Beacon street many of the better residences of Boston. The rise of the tide is normally about 10 feet.

The project of building a dam across the Charles river was discussed for many years beginning in 1859. A project was prepared in 1870, but was rejected by a vote of the people of Boston. With increasing population in the Charles river valley above Boston, the amount of sewage flow became such that the banks of the river and exposed flats became more and more offensive. In the summer of 1892 the nuisance became so offensive that the windows had to be closed during periods of low tide in the river. Apprehension as to the effect upon the health of residents in the neighborhood from gaseous emanations produced much

discussion, and caused petitions for relief, signed by householders and nearly all practising physicians in the affected district, to be addressed to the State Board of Health.

In 1891 the city of Boston appointed the Charles River Improvement Commission, which made two reports recommending embankments along the river and certain other changes.

The Legislature of 1893, without acting on these recommendations, appointed a joint board consisting of the State Board of Health and the Metropolitan Park Commission to investigate conditions and prepare plans for the improvement of the bed, shores and waters of the river, and for the removal of any nuisances therefrom. This Board recommended a dam to create a basin with a constant level. Much agitation and many hearings followed this recommendation. Views varied widely as to the desirability of such a basin, and also as to the effect which it might produce on Boston harbor with respect to shoaling.

In 1901 the Legislature appointed the Charles River Dam Committee, which investigated the matter with much thoroughness from an engineering, chemical and biological standpoint. The decision as between a fresh water and a salt water basin led to many important investigations of a chemical and biological nature. The former were conducted by Mr. H. W. Clark, Chemist of the State Board of Health, and for the latter the services were secured of Dr. George W. Field. The sanitary engineering aspects were considered by Mr. X. H. Goodnough and the pathological features, with particular reference to malarial problems, were investigated by Dr. Theobald Smith, of the Harvard Medical School. All of these investigations were under the direction of Mr. John R. Freeman, Chief Engineer for the Committee. The report of Mr. Freeman in 1903 is one of the best investigations of this subject that has yet been undertaken. It brought to the front information that was at variance with prior general views. The details are well worth careful study. We shall quote the summary by Mr. Freeman of the evidence showing the comparative advantages of fresh-water and salt-water basins on pages 76–81 of the 1903 report as follows:

FRESH-WATER BASIN VS. SALT-WATER BASIN. COMPARATIVE ADVANTAGES

Many persons have the idea that a salt-water basin is more healthful and that the mere presence of salt in the water of the basin would tend

to prevent or retard the decay of any putrescent matter that might enter it. The statements of Dr. H. O. Marcy (see report of evidence at hearings of 1894, pp. 27, 30) reflect the prevailing view.

In order to meet this, the proponents at the hearings of 1902 gave much attention to the feasibility of providing large tidal sluices in the dam.

I had some predisposition to favor a clean salt-water basin on anything like equal terms, particularly after having observed the pleasure of the children bathing and learning to swim at the Captain's island playground; but a preliminary study soon led me to conclusions so different from the popular view, as expressed above, that I requested the pathologist, the biologist and the chemist each to take up this question from his own field of view, and to make his investigations independently of his associates. *Each of these experts independently reported that, in his opinion, the fresh-water basin would prove the better.*

If absolutely pure ocean water could be had in the Charles and kept free of pollution, a different conclusion might have been reached; but this is plainly impossible, and the varying quantity of upland water precludes a brackish basin of the constant salinity requisite for the best development of marine life.

The chemist, Mr. H. W. Clark, in order to answer this question of the comparative merits of fresh and salt water, undertook several lines of experimental work, which will be found described in some detail in Appendix No. 4. The principal results were as follows:

(a) It was found that, temperature and other conditions being equal, *salt water holds somewhat less oxygen in solution than fresh water*, and therefore, volume for volume fresh water can receive the greater volume of pollution without the exhaustion of this oxygen if bacterial life is of equal vigor in each case (page 272).

(b) Several lines of experiments were undertaken for determining the effect of mixing various definite percentages of sewage with fresh water and with salt water, the aim being to learn how large a percentage of sewage could be mixed with each, under various conditions and for different lengths of time, without exhausting the oxygen primarily present in this water and without producing odors from putrefaction (page 270).

The first series of experiments was made with the mixtures in large, tightly stoppered bottles, which were "incubated" and maintained at a constant temperature of 80° F. for five days, in order to give very favorable conditions for decomposition. The simple test of smelling of the respective samples, from time to time, gave strong presumptive evidence in favor of the fresh water; but, as a means of accurate demonstration, careful measurements of the percentage of oxygen remaining in the water of each test bottle were made frequently, because it is

when the free oxygen originally dissolved in the water becomes nearly or quite exhausted that putrefaction with its offensive odors chiefly begins.

In every case and with all the various percentages of mixture it was found that the oxygen disappeared very much more rapidly in the salt water than in the fresh water.

Other similar tests were made, in which the test bottles were left unstoppered, in order that the surface of the water might be open to the air and free to absorb new oxygen from it. The open bottles did not develop such offensive odors as the closed bottles, but *the odors from the mixture with salt water were in all cases decidedly the worse;* and in general, throughout the variety of experiments performed on comparative mixtures of sewage with fresh water and with salt water, it was found that while when first mixed the faint sewage odor was most noticeable in the fresh water, this odor generally became less, while with sea-water mixtures the odor invariably grew worse with time (see pages 272, 291, Appendix No. 4; also page 342, Appendix No. 6).

Another series of experiments was on the comparative merits of salt water and fresh water for taking care of the pollution found in certain of the mud banks of the Charles. Equal quantities (2 grams) of the polluted mud from the Charles were shaken up with equal quantities (1/2 gallon) of fresh water and salt water in stoppered bottles, which were then incubated at a constant temperature of 80° F. for five days, after which portions were siphoned off for dissolved oxygen determinations.

This experiment was made in duplicate, salt and fresh, with nine different samples of mud taken from the most polluted mud banks of the Charles and the Fens. *In every case the incubation in sea water exhausted more oxygen than incubation in fresh water, and also exhausted a larger proportion of the oxygen originally present.*

A period of reincubation was then tried on the same samples, by adding one gram more of the respective samples of mud to each bottle aerated again, stoppering and incubating for ten days at 80° F. After ten days the quantity of dissolved oxygen remaining in each sample was tested again, and it was found that in every case a larger proportion of the oxygen was exhausted from the salt water than from the fresh. The odors of the various samples of water were noted after the first incubation and also after the second incubation, and *in every case the salt water had the most offensive smell.*

The lesson from this series of experiments is plainly that the polluted mud flats of the Charles and of the Fens are more likely to rob the water immediately over them of this dissolved oxygen, and more likely to give rise to offensive odors, if the basin is filled with sea water than if it is filled with upland water.

The chemist also prepared a series of laboratory tests in glass tanks 18 inches deep for comparing the bacterial growth in sea water over polluted mud, and in fresh water over the same kind of polluted mud, all mud being taken from the bed of the Charles river. Some of these experiments were continued four weeks, test samples for bacterial counting being frequently taken. It was found that of the anaerobic growths, which are the ones which produce putrefaction, the greater number occurred in the sea-water tanks, both in the water and in the mud, and the greatest exhaustion of oxygen occurred in the sea water.

My observations upon the deposition of sludge going on continually in the outlet of the new Stony brook channel and an examination of the vast foul sludge banks now found in the salt Fens basin, and also observations upon some of the smaller sludge banks that now exist near certain of the sewage outlets along the salt Charles basin, prompted a request that the chemist investigate the effect of salt in the water upon throwing down any suspended pollution or turbidity to the bottom as a sludge.

The results of these experiments are briefly reported on pages 286, 287 of Appendix No. 4, and are particularly well shown by the photographs of the samples compared.

It was found that the presence of salt in the water had a strong influence as a precipitant of such matters as Charles river mud and sewage pollution; and, while the effect of this precipitant would be to make the surface water of these large basins more clear, it at the same time concentrates the polluting particles into sludge banks, which are less easily acted upon by those bacteria or other growths which produce inoffensive, odorless decomposition, and in these concentrated mud banks there must be more of a tendency to putrefy.

In the present condition of the Fens basin and its sludge banks, with bubbles arising from them, may be found a most instructive example of the way that sea water acts upon polluted fresh water.

The biologist also made some experiments on the effect of mixing the same proportion of sewage with upland water and with salt harbor water. These are very briefly described on pages 341-42 of Appendix No. 6. He found that "*under identical conditions, sewage introduced in fresh water was less offensive than when introduced into water from the Charles estuary or the harbor.*"

The biologist admittedly approached this question of the fresh-water basin *v.* a salt or brackish water basin with some bias in favor of a basin containing a considerable percentage of salt water mixed with the fresh water, expecting, from some of his previous experiments, that a brackish-water basin would support the maximum quantity or organic life, and that therefore its contents would absorb or devour a maximum pollution, or plant food, without the production of offensive odors; but

soon after beginning his studies he reported unsurmountable obstacles to the success of this brackish-water plan.

(a) That the sea water entering the harbor from off Boston Light, being largely from the cold northern ocean current, was more nearly sterile than the warmer water of points south of Cape Cod, with which naturalists had made the most observations and experiments; and that therefore this water from Boston harbor would be less immediately available for absorbing the impurities and rendering them innocuous, through appropriate bacterial action.

(b) That the varying rate of flow of upland water would make it well-nigh impossible to preserve the uniform degree of salinity necessary for the most favorable growth and activity of organic life; that, with violent changes of salinity many of the beneficent low forms of life would be killed off.

(c) That it was not practicable to secure such thorough mixture of the fresh upland water with the salt harbor water as to avoid differences of specific gravity which would prevent vertical circulation, and thus prevent water in the lower layers of the basin from coming into contact with the air, whereby their dissolved oxygen could be renewed.

The biologist found his main field for demonstration in the Fens basin itself. In the contents of this basin, which are about three-quarters salt harbor water, he found that, notwithstanding the motion of circulation is more rapid than it would be in the proposed Charles basin, the salt-water layers remained beneath the fresh-water layer; that vertical circulation and reaeration of the lower layers of the water were thereby cut off, and that these deeper layers were devoid of oxygen, and populated almost solely by the anaerobic or putrefactive bacteria, and would in warm weather continually give off hydrogen sulphide and other foul-smelling gases (see page 326, Appendix No. 6).

The pathologist (page 113, Appendix No. 1) reports that the malarial mosquito breeds most freely in fresh water, rarely in salt or brackish water—which would appear an argument in favor of a salt-water basin; but, after carefully weighing the probable results of changing the Charles from a salt-water estuary to a fresh-water basin of constant level, and after making many bacterial tests of the quality of the harbor water, he concluded (page 129) that "*the introduction of salt water from the harbor will not be needed, and should only be reserved as an artificial remedy for extreme, unforseen conditions.*"

As a result of these carefully formed expert opinions, and from conference with other engineers who have had opportunity for observing the effect of sewers discharging into salt water; and from the reported fact that a marked difference is noted in the odors arising from the manholes of the Boston main drainage and metropolitan sewers to which some proportion of salt water has been admitted, in comparison with

the manholes of the common sewers that receive no salt water and from such investigations as I have been able to make upon the formation of the present sludge banks in the Charles basin and in the Fens; and from the broad common-sense view that any such varying percentage of salt as would of necessity follow the varying inflow of fresh upland water must interfere with the activities of organic life; and that, of necessity, an imperfect mixture with different specific gravities at the top and bottom would bring defective vertical circulation, and therefore defective oxygenation, and that from this there would of necessity follow a tendency to putrefaction, with its offensive odors—*the conclusion has been reached as clear, beyond doubt or question, that the fresh-water basin will be very much better, under the circumstances, and that by means of a marginal conduit and other means proposed for lessening pollution this water at Captain's island and other future points available for bathing can be kept cleaner and more wholesome than it is to-day, even on an incoming tide.*

As stated on page 47, and also on page 145, Appendix No. 2, it appears more hopeful to absorb, devour and render the entering pollution inoffen-

FIG. 11.—Charles river bank before improvement.

sive by means of the activities of organic life, very much as manure or plant food is absorbed in the garden, than to salt this water, and thus precipitate, concentrate and defer the oxidation of the impurities.

Construction.—The Charles river dam is an earth embankment with masonry retaining walls about 1200 feet long and from 100 to 500 feet in width. On the Boston side is a large boat

lock and on the Cambridge side a small boat lock. There is also a salt-water sluice with its bottom about 26.5 feet below the surface. The shut-off gates were dropped on Oct. 20, 1908. Fig. 11 furnished by the courtesy of the State Board of Health and the Metropolitan Commission shows the Boston water front before improvement. Fig. 12 is a view of the same stretch at present, from the final report of the Committee in 1910.

Distribution of Sea Water.—The distribution of sea water in the Charles river basin after excluding tidal waters has been studied with care by Mr. M. F. Sanborn. His results are recorded

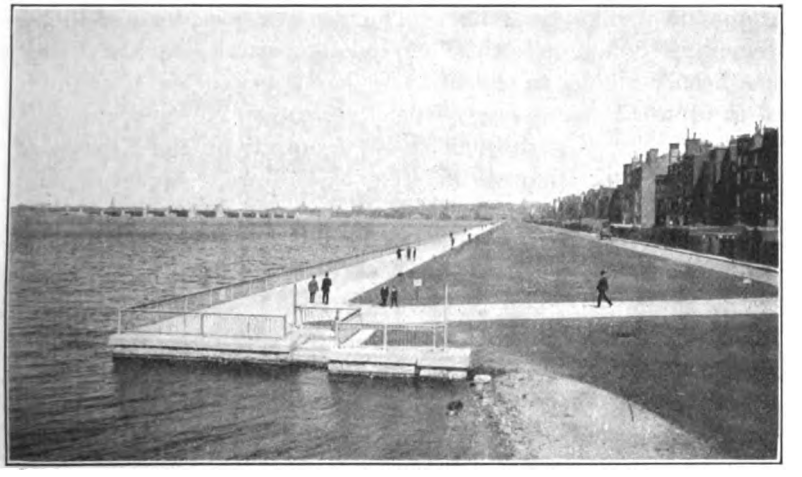


FIG. 12.—Charles river bank after improvement.

in *Engineering News* of Mar. 10, 1910. The data as to circulation caused by wind and waves and the interchange of fresh and salt water are valuable additions to available information.

NEW YORK HARBOR AND VICINITY

Several volumes have been written on the disposal of the sewage of the metropolitan district of New York. Efforts to improve the conditions date back to 1887 when the late General Newton, at that time Commissioner of Public Works, retained Mr. Rudolph Hering to report on this question for the old city of New York.

Report of 1887.—This report resulted in a recommendation

of the extension of the principal sewer outlets from the bulkhead to the pierhead line, securing submergence where needed, thus reducing the pollution of the docks and slips. It took more than 20 years to carry out this recommendation in a piecemeal fashion.

Opposition to Trunk Sewers.—Technical journals and the daily press have had much to say in recent years as to the pollution of New York harbor, particularly in connection with two trunk sewers. One of these is in the Bronx valley just above the northern limits of the city of New York and which diverts sewage through a tunnel to the Hudson river a short distance from the Yonkers city line. The other project, located in New Jersey, is spoken of as the Passaic valley trunk sewer and which has been designed to collect the entire dry-weather sewage flow of the lower Passiac valley from Paterson to Newark, inclusive, and to discharge it through multiple outlets on the New Jersey side of the main channel of upper New York bay in a depth of more than 40 feet of water off Robbins reef.

The State and city of New York have both opposed these projects and have been instrumental in seeking restraining orders from the courts. The Bronx valley trunk sewer was designed with its outlet terminating at the bulkhead line about 170 feet from the river's edge, in about 13.5 feet of water. In September, 1911, the New York State Supreme Court prohibited the discharge of sewage through this outfall after Sept. 15, 1911, and directed that treatment works be built at once. These are understood to involve screening, sedimentation, and an extension of the outfall into deeper water.

The injunction suit was brought by the Leake and Watts Orphan Asylum located near the river front in question. It was based on the ruining for the institution of the bathing facilities in the river and on non-compliance with the terms of the permit of United States War Department.

Fig. 13 shows a sketch of New York harbor and vicinity.

THE PASSAIC VALLEY PROJECT

In *Engineering News* of Feb. 23, 1911, will be found the main items in the history of recent developments as to this project. Briefly, it may be said that the lower Passaic river at Belleville just above Newark was the source of the public water

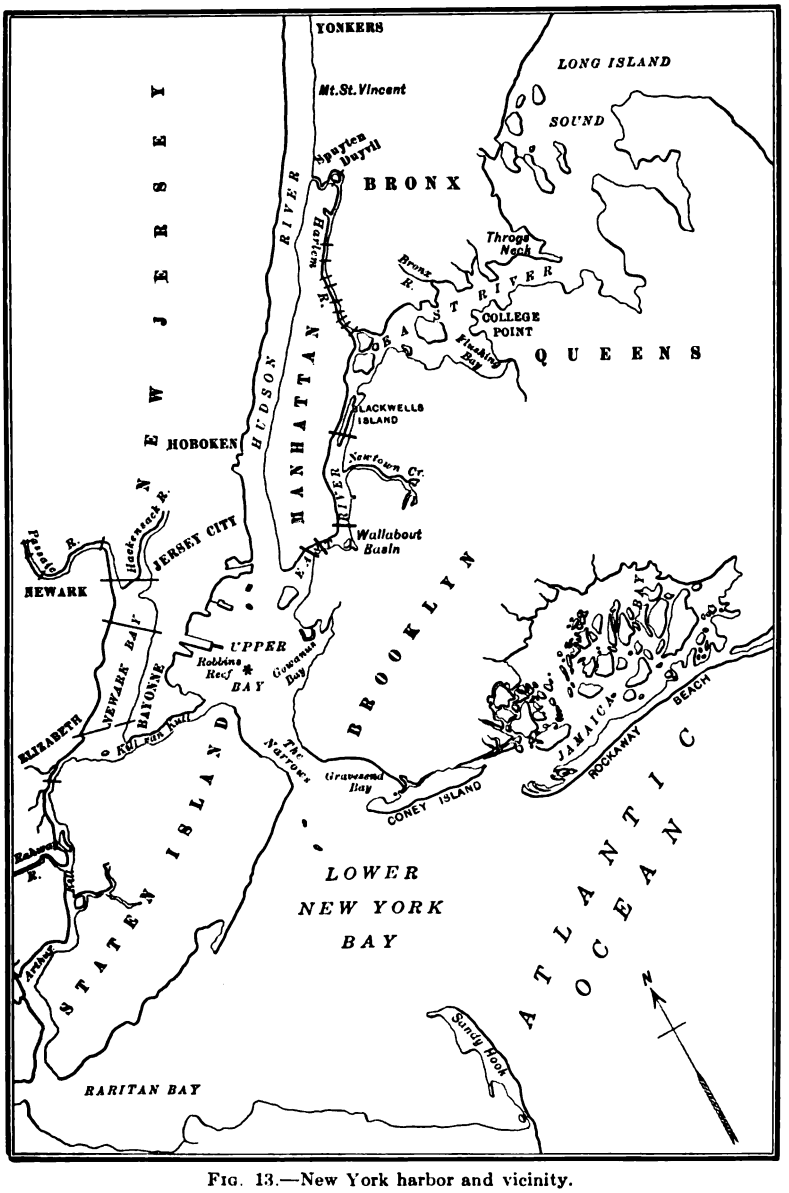


FIG. 13.—New York harbor and vicinity.

supply of Newark until 1892 and of Jersey City until 1895. The rapid growth of the cities of Passaic and Paterson above and, in fact, of the entire lower valley, quickly changed this stream so that for the past dozen years it has ordinarily been a black, foul-smelling channel differing but little from an open sewer.

Report of 1897.—In 1896 a commission was appointed to recommend means for cleaning the river in the lower valley. The late Mr. Alphonse Fteley and the late Mr. Chas. E. A. Jacobsen were the engineers. They prepared a careful comprehensive report recommending an intercepting sewer from Paterson to theNewark Meadows and dispersion or dilution of the sewage in the waters of lower Newark bay. This met with some opposition from certain interests in that locality, particularly in Bayonne, and the matter was again reviewed by the newly established State Sewerage Commission of New Jersey.

Report of 1901.—Messrs. Rudolph Hering, J. J. R. Croes and William M. Brown were retained to investigate the matter. They advised in favor of dispersion in the upper New York harbor near Robbins reef light.

Passaic Valley Commission.—The Passaic Valley District Sewerage Commission was then organized. Some of the more essential engineering features were prepared in 1902 under the direction of Mr. Rudolph Hering as Chief Engineer. A plan of procedure was reported to the Legislature of 1903. Some delays incidental to the constitutionality of the proposed mode of payment for the needed works on the assessment basis then followed. Legal and legislative questions occupied attention for several years until 1907, when still further details of an engineering nature were prepared by Messrs. Hering & Fuller. They served as the basis of a formal report of April, 1908, wherein the Commission notified the cities and towns of the scope and cost of the proposed works. The absence of funds forced these matters into an abnormal and unfortunate position, whereby only the more essential features could be developed.

Further engineering details were prepared under the direction of Mr. Edlow W. Harrison in 1909–10, after the legislature passed an act enabling Newark and some other cities to advance funds for the same.

During all these years various communities in the lower Passaic valley gave much debate to the project, particularly the city of Paterson, which was under orders from the court

to cease the pollution of the river by March, 1911. This is an earlier date than that set forth in the enabling act of the Passiac Valley Sewerage Commission for the removal of all sewage from the lower valley. The latter date was first established as Dec. 1, 1912, but was changed to Dec. 31, 1914.

Mr. Allen Hazen prepared a valuable report for Paterson in 1906 in which he recommended, in the absence of legal complications, Paterson to join in a trunk sewer to New York harbor rather than to provide an independent sewage disposal plant.

Litigation now developed from New York, based largely on supervisory powers which New York State claims to possess over the harbor to the low-water line of the New Jersey shore. This claim is disputed. It relates to a treaty between the two states executed in 1833 and confirmed by Congress whereby quarantine and police jurisdiction over the upper harbor is vested in the State of New York, but with a number of distinct stipulations as to limitations, among them that the right of property is to remain west of the boundary line in the State of New Jersey.

A suit for injunction was brought against the State of New Jersey and the Passaic Valley Sewerage Commissioners by the State of New York in the United States Supreme Court in 1908. Agitation of this question by New York City became quite keen and the United States Government was prevailed upon to appear in this suit as an intervenor. It is stated that this step was based on the protection of government property in the harbor.

Numerous conferences were held with a view to considering ways and means of procedure, the efforts being made on the part of the Passaic Valley officials to cause the United States Government to retire as an intervenor and through its War Department to issue a certificate of approval as required by law. In the absence of this permit contracts could not be made and the whole proposition was on an uncertain footing.

Col. William M. Black, Engineer Corps, United States Army, Chief Engineer Officer of the Department of the East and a member of the New York Harbor Line Board, was requested by Gen. Leonard Wood, then Commandant of the Department of the East, to report upon the merits of this proposition in the interests of the United States Government. This report, which is summarized in *Engineering News* of Oct. 21 and the *Engineering Record* of Oct. 23, 1909, made an earnest plea for

an equitable and uniform step looking to an improvement of the sanitary conditions of New York harbor. After various discussions with a view to satisfying the requirements of the Chief Engineer of the United States Army, Gen. Marshall signified his consent to the Passaic valley sewerage project and by virtue of certain agreements entered into by the State of New Jersey and the United States Government, the latter withdrew as an intervenor in this suit and a certificate of approval of the War Department was issued. This document is of considerable interest in showing what steps the State of New Jersey and the Passaic Valley Sewerage Commissioners were willing to take as regards a guarantee against nuisance in New York harbor due to the sewage from this district. It is given in full, as follows:

THE UNITED STATES PERMIT FOR THE PASSAIC VALLEY PROJECT

Whereas, By Section 10 of an act of Congress, approved March 3, 1899, entitled "An act making appropriations for the construction, repair, and preservation of certain public works on rivers and harbors, and for other purposes," it is provided that it shall not be lawful to build or commence the building of any wharf, pier, dolphin, boom, wier, breakwater, bulkhead, jetty, or other structures in any port, roadstead, haven, harbor, canal, navigable river, or other water of the United States, outside established harbor lines, or where no harbor lines have been established, except on plans recommended by the Chief of Engineers and authorized by the Secretary of War; and it shall not be lawful to excavate or fill, or in any manner to alter or modify the course, location, condition, or capacity of, any port, roadstead, haven, harbor, canal, lake, harbor of refuge, or inclosure within the limits of any breakwater, or of the channel of any navigable water of the United States, unless the work has been recommended by the Chief of Engineers and authorized by the Secretary of War prior to beginning the same;

And whereas, the Passaic Valley Sewerage Commission has applied to the Secretary of War for permission to locate a sewer outlet with shaft house in New York Bay, in the vicinity of Robbins Reef Light, and to construct the necessary appurtenant works, in accordance with the attached agreement and plans, which have been approved by the Chief of Engineers, United States Army;

Now, therefore, this is to certify that the Secretary of War hereby gives permission unto the said *The Passaic Valley Sewerage Commission* to locate a sewer outlet with shaft house in *New York Bay*, in the vicinity

of Robbins Reef Light, and to construct the necessary appurtenant works, in accordance with said agreement and plans; subject to the following conditions:

1. That the work herein permitted to be done shall be subject to the supervision and approval of the Engineer Officer of the United States Army in charge of the locality.

2. That if at any time in the future it shall be made to appear to the Secretary of War that the work herein authorized is an unreasonable obstruction to the free navigation of said waters, said licensee will be required, upon due notice from the Secretary of War, to remove or alter the same so as to render navigation through said waters reasonably free, easy, and unobstructed.

3. That the tunnel under Newark Bay shall be constructed so as to give a clear depth of not less than thirty-five (35) feet at mean low water in the navigable channel.

4. That the gate house near Robbins Reef Light shall be erected at the point and under such plans as the Secretary of War, after consultation with the Secretary of the Department of Commerce and Labor, may hereafter approve; except as may be required in any particular by the terms of a stipulation or contract, of which a copy is hereto attached, made between the United States and the Passaic Valley Sewerage Commissioners under date April 14, 1910, whereby the parties to that stipulation or contract adjusted the matters controverted between them in the suit of The People of the State of New York (United States, Intervenor) *v.* The State of New Jersey and Passaic Valley Sewerage Commissioners, being Number 6 on the Original Docket of the Supreme Court of the United States for the October Term, 1909.

5. That the Passaic Valley Sewerage Commission shall remove from the waters of New York Harbor any shoals when the Secretary of War shall be satisfied that the same result from the discharge from the proposed tunnel and shall direct their removal.

6. That all the terms and requirements of the divisions numbered First and Second of said stipulation or contract between the United States and the Passaic Valley Sewerage Commissioners, mentioned above, shall be at all times met and satisfied, according to the true import of said contract.

It is Understood that this instrument simply gives permission under said Act of Congress to do the work herein authorized; that it does not give any property rights, and does not authorize any injury to private property or invasion of private rights.

Witness my hand this 11th day of May, 1910.

(Signed) J. M. DICKINSON,
Secretary of War.

IN THE SUPREME COURT OF THE UNITED STATES.
October Term, 1909.

THE PEOPLE OF THE STATE OF NEW YORK, Complainants, *v.* THE STATE OF NEW JERSEY AND PASSAIC VALLEY SEWERAGE COMMISSIONERS, Defendants.	In Equity No. 6 Original on the Docket for said October term.

STIPULATION

The United States having intervened in the above entitled suit with the consent of the court, and it being desired by the United States and the defendants in the suit to adjust the matters in controversy between them, in the manner and upon the terms and conditions hereinafter stated, and the State of New Jersey, by an act of its Legislature, approved on the eighth day of April, nineteen hundred and ten, having authorized the defendant, the Passaic Valley Sewerage Commissioners, to make this adjustment, *it is now stipulated and agreed* by and between the United States and the Passaic Valley Sewerage Commissioners, defendants in the suit, as follows:

First: The Passaic Valley Sewerage Commissioners agree with the United States that the sewer system to which the suit relates shall be constructed, maintained and operated, if at all, in accordance with the following requirements:

(a) Upon the line of the trunk sewer which it is proposed shall be constructed, and at a point at or near the pumping station to be located on the Newark Meadows near the Newark Bay, it is stipulated and agreed that the sewage, waste and other matter passing through the said trunk sewer shall first pass through coarse screens to remove therefrom all large floating matter, and after passing through such coarse screens shall pass through a grit basin or basins where the heavy matter therein shall be taken out as far as practicable, from which basin or basins the sewage and other matter shall pass through self-cleansing mechanical screens having clear openings of not over 0.4 of an inch.

(b) As the sewage comes from the fine screens, it shall also pass through sedimentation basins. The sewage after passing through said grit basin and said self-cleansing mechanical screens shall enter the sedimentation basins or settling tanks consisting of a number of units, each approximately 225 feet long and 15 feet deep. Each tank will have a normal capacity of not less than 1,250,000 gallons, making an aggregate tank capacity sufficient to meet the requirements as stated herein. The tank capacity shall always be such as to provide a detention period of not less than one hour at the maximum rate of flow

of the sewage and a detention period of the daily average flow of such sewage for not less than one hour and a half. The mean lineal velocities through said tanks shall not be over 0.5 inch per second for average flow, and 0.75 inch per second for the maximum flow. In addition to and in connection with these basins scum boards shall be provided to retain the floating matter, and proper and adequate devices shall be used to remove the retained scum and deposits from the settling basin; drawings of the general plan of said settling tanks (sedimentation basins) as proposed at the outset being herewith attached as Appendix A.

(c) The sewage and waste thus screened and settled is then to flow into a pump well, whence it is to be pumped under pressure through a tunnel to a point in the New York Bay near Robbins Reef Light, at which point it is agreed that the matter passing through the said tunnel shall be dispersed into the waters of the New York Bay through a series of outlets discharging 40 feet or more beneath the surface of the water at mean low tide. From the end of the tunnel connections shall be made with four or more discharge pipes extending across the current, spaced about one hundred feet apart, laid in trenches on the bottom of the Bay, and of a size decreasing in diameter from about 6 feet to 2 feet. On the top of these discharge pipes will be a series of not less than 150 tees of a diameter not exceeding 1 foot and spaced approximately 10 feet apart. On each of these vertical tees shall be placed outlets arranged to discharge horizontally across the tidal current, and the extent of the dispersion area used for this system of outlet pipes shall cover at least 3.5 acres of the bottom of the Bay.

Second: The Passaic Valley Sewerage Commissioners further agree with the United States that in the operation of said sewer system at all times the following results shall be secured, either through compliance with the requirements of the immediately preceding paragraphs, or through requisite lawful additional arrangements, viz:

(1) There will be absence in the New York Bay of visible suspended particles coming from the Passaic Valley sewage.

(2) There will be absence of deposits objectionable to the Secretary of War of the United States in the New York Bay coming from the Passaic Valley sewage.

(3) There will be absence in the New York Bay and its vicinity of odors due to the putrefaction of organic matters contained in the Passaic Valley sewage thus discharged.

(4) There will be a practical absence on the surface of New York Bay of any grease or color due to the discharge of the Passaic Valley sewage at the dispersion area or elsewhere.

(5) There will be no injury to the public health which will be occasioned by the discharge from the said sewer into the Bay of New York in the manner proposed and no public or private nuisance will be created thereby.

(6) The absence of injurious effect from said sewage discharge, upon the property of the United States situated in the Harbor of New York.

(7) The absence of reduction in the dissolved oxygen contents of the waters of New York Bay, resulting from the discharge of Passaic Valley sewage, to such an extent as to interfere with major fish life.

Third; The said Passaic Valley Sewerage Commissioners further agree with the United States that so long as said sewer system, or any part thereof, is operated, the United States shall have, through such representatives as may be designated by the Secretary of War at any time for such purpose, full opportunity to inspect the condition and working of the sewer system, with a view to determining whether this contract is being in all respects performed, and that the said Passaic Valley Sewerage Commissioners will render such expert or other assistance as the United States may desire in the course and in aid of such inspection and determination.

Fourth; The United States agrees with the Passaic Valley Sewerage Commissioners that forthwith upon the filing of this agreement, properly executed, in the effice of the Clerk of the Supreme Court as a stipulation of the parties in the suit, it will discontinue its intervention in the above entitled suit and will cause its petition of intervention to be dismissed without prejudice, and will not again intervene in said suit.

Fifth; The United States and the Passaic Valley Sewerage Commissioners mutually agree that this contract shall not become effective in any part, except the next succeeding divisions, unless or until all such permits as would be requisite under the statutes of the United States for the construction, maintenance or operation of said sewer system without this contract are actually obtained from the United States, or unless or until such permits are made conditional upon compliance at all times with all the terms and requirements of the divisions of this contract numbered First and Second, whether or not such permits contain others terms or conditions.

Sixth; The Passaic Valley Sewerage Commissioners hereby consent that full compliance at all times with the terms and requirements of the First and Second divisions of this contract be made express conditions of any permits issued by or on the part of the United States for construction, maintenance or operation of said sewer system, and agree with the United States that this contract shall establish such consent before all officers of the United States.

Seventh; It is agreed between the United States and the Passaic Valley Sewerage Commissioners that this contract shall bind and also shall enure to the benefit of the successors of the latter.

In witness whereof this instrument has been executed in triplicate; being signed in the name and on behalf of the United States by the Attorney General of the United States and in the name and on behalf

of the Passaic Valley Sewerage Commissioners by their president, and being sealed also on behalf of said Passaic Valley Sewerage Commissioners with their corporate seal attested by their secretary; all on the fourteenth day of April, nineteen hundred and ten.

THE UNITED STATES OF AMERICA,
by Geo. W. Wickersham,
Attorney General.
PASSAIC VALLEY SEWERAGE COMMISSIONERS,
by Julius A. Lebkuecher,
Chairman and President.

Attest:
JOHN S. GIBSON,
Secretary and Clerk.

NO. 6, ORIGINAL

IN THE SUPREME COURT OF THE UNITED STATES.
October Term, 1909.

THE PEOPLE OF THE STATE OF NEW YORK, Complainants,
THE UNITED STATES, Intervenor,
vs.
THE STATE OF NEW JERSEY AND PASSAIC VALLEY SEWERAGE COMMISSIONERS, Defendants.
} In Equity.

In behalf of the State of New Jersey I approve of and consent to the making of the foregoing stipulation, and consent that the United States discontinue its intervention in the above entitled cause, and that the petition of intervention of the United States be dismissed without prejudice.

Dated April 14, 1910.

ROBERT H. MCCARTER,
Special Counsel.

RESULT OF STIPULATIONS

It was understood at the time that these stipulations were entered into that the State of New York would withdraw from the suit in question. It was further understood that the New York representatives desired to sign jointly with the Federal government the stipulations above set forth. To this the New Jersey representatives would not consent, as it would establish a precedent according to their views which was not intended by the treaty of 1833, and which in the absence of

such treaty would be inadmissible on the ground that the sovereign rights of New Jersey could not be made subservient to those of the State of New York. Upon changing attorneys the matter remained in this condition for some months, with more or less misunderstanding. Testimony was begun in June, 1911.

This matter being in litigation, no further mention in detail will be made of the subject other than to say that after the preparation of fairly complete working plans for this project under the direction of Messrs. Edlow W. Harrison and William Gavin Taylor, as engineers, dissension arose among some of the communities within the district, when it came to executing contracts with the Commission for building the works. In part this may have been influenced somewhat by the litigation, but it was principally due to the feeling that residential communities, such as Montclair and East Orange, would be compelled to pay on the assessment or ratable basis more than their fair share of the cost of construction work. In the case of Bloomfield it would be cheaper to pay on a "ratable" than on a "usage" basis. For Glen Ridge and Orange the difference between the two methods is comparatively slight. This state of affairs caused a rearrangement of the pact, with 15 of the so-called river towns joining in the trunk sewer project and beginning their pro rata payments for the execution of this work in November, 1911. Certain of the remaining five towns spoken of as the "upland" towns then refused to come into the pact on the theory that collectively they could build local disposal works to give satisfactory results at less cost to them than the trunk sewer project. This financial advantage is associated with the assumption that the upland towns take advantage of their topographical position and deliver their sewage to a joint purification plant located at a lower level in a neighboring town. If each upland town disposed of its sewage in a plant of its own, within its own town limits, the economical advantages above set forth are said to largely, if not wholly, disappear.

The Engineer Officers of the United States Army and the Secretary of War approved the detail plans of the Passaic valley project under date of Sept. 22, 1911.

We will now refer briefly to the efforts made by the state and city of New York to investigate and improve the sanitary conditions of the New York harbor.

NEW YORK BAY POLLUTION COMMISSION

Following the passage of an act by the New Jersey Legislature in 1903 enabling the Passaic Valley Sewerage Commission to execute the construction of a trunk sewer to discharge into New York bay, there was appointed by the New York Legislature in May, 1903, a commission to investigate and report upon this subject. This New York Bay Pollution Commission made two reports. The first was in March, 1905, in which a general discussion of the New York viewpoint was given. It consists essentially of a protest against the Passaic Valley project and recommends that suit in the United States Supreme Court be brought if New Jersey should press forward to execution the trunk sewer with its outlet in New York bay. Considerable interest attaches to comments in this report on the rights of New York due to the interstate treaty of 1833.

It contains a series of appendices in which are recorded various data and views on the volume of sewage and diluting water, analyses of harbor water, relation to shellfish and other industries, and the possibilities of local improvement and disposal at sea of all the sewage of the metropolitan district. It recommends for New York a metropolitan sewerage commission to continue the examinations and to report on possible methods of disposal, and if practicable to work in conjunction with a similar commission of the State of New Jersey.

In April, 1906, there was a second report. In it are renewed the recommendations for a metropolitan commission. A number of examinations of the waters in and surrounding New York harbor were carried on under the direction of Dr. George A. Soper, who summarizes, in the appendix, these investigations as follows:

The principal conclusions which it seems proper to draw from the foregoing investigations are in conformity with the conclusions recorded in the first report of the commission. They are as follows:

1. The waters of the bay and adjacent waters are unmistakably, but not as yet badly, polluted.

2. The sewage is not uniformly dispersed and diffused throughout the depth and breadth of the tidal currents. The discharge of crude sewage results in polluting the water more at the surface than in the depths below.

3. The discharge of sewage along the shores often leads to the production of a decided local nuisance.

4. Although the present method of disposing of the sewage of Manhattan is, perhaps, as acceptable as any method of emptying crude sewage into these waters could be, it is far from being always satisfactory.

5. The disposal of sewage at the pierhead line, as practised on Manhattan Island, is much to be preferred to the plan of emptying it at the bulkhead line as is generally practised elsewhere in this vicinity.

6. There is no doubt but that offensive matters from the sewage, and the sewage itself, are sometimes transported long distances by the tides and winds and deposited on shores remote from any sewer outlet.

7. Excepting in such heavily polluted waters as Gowanus Canal, there is probably always enough oxygen in the water to enable the bacteria of decomposition to carry on their work without the production of offensive odors.

8. No other method of disposing of the sewage of New York and vicinity is suggested as the result of these investigations. It is evident that some other method should be devised, if practicable, but the satisfactory study of this question involves investigations of a far more exhaustive character and of a wider scope than have thus far been possible.

METROPOLITAN SEWERAGE COMMISSION

This commission was established in 1906 by an act of the New York Legislature directing the City of New York to appoint a commission to deal with certain specified problems. In January, 1908, it was reorganized on present lines, and it made a comprehensive report of some 550 pages published under the date of April, 1910.

This report deals with elaborate data on areas, populations, present sewers, sewage flows and sanitary conditions, as shown by inspection and analyses. Tidal flows were studied, as were currents, the degree of salinity of the water at various points, and factors affecting dispersion and assimilation.

Dissolved Oxygen.—The atmospheric oxygen dissolved in harbor waters was studied with care at different points. It follows the general procedure of the British Royal Commission on Sewage Disposal. Its results are expressed in cubic centimeters per liter, rather than in parts per million, as recommended by the Committee on Standard Methods of Water and Sewage Analyses of the American Public Health Association. From the Fifth Report of the Royal Commission on Sewage Disposal of Great Britian are taken data to show the volume of oxygen

absorbed from air when saturation is reached at different temperatures when the water is of different degrees of salinity. This table, which is of much value for reference, is as follows:

TABLE 51.—VOLUMES OF OXYGEN ABSORBED FROM THE AIR BY DISTILLED WATER AND BY SEA WATER AT DIFFERENT TEMPERATURES CENTIGRADE AND AT A PRESSURE OF 760 MILLIMETERS.

(From the Fifth Report of the Royal Commission on Sewage Disposal, 1908)

Temperatures in degrees centigrade	Percentages of distilled water to sea water															
	0	4	8	12	16	20	24	28	32	36	40	44	52	64	72	100
17	5.6	5.6	5.7	5.7	5.8	5.9	5.9	6.0	6.0	6.0	6.1	6.2	6.3	6.4	6.5	6.9
18	5.5	5.5	5.6	5.6	5.7	5.8	5.9	5.9	5.9	6.0	6.0	6.0	6.2	6.3	6.4	6.8
19	5.4	5.4	5.5	5.5	5.6	5.6	5.7	5.8	5.8	5.8	5.9	6.0	6.0	6.2	6.3	6.7
20	5.3	5.3	5.4	5.4	5.5	5.5	5.6	5.7	5.7	5.8	5.8	5.8	5.9	6.0	6.2	6.5
21	5.2	5.2	5.3	5.3	5.4	5.4	5.5	5.5	5.6	5.6	5.7	5.7	5.8	6.0	6.1	6.4
22	5.1	5.1	5.2	5.3	5.3	5.4	5.4	5.5	5.5	5.6	5.6	5.6	5.7	5.8	5.9	6.3
23	5.0	5.0	5.1	5.1	5.2	5.2	5.2	5.3	5.4	5.4	5.6	5.6	5.6	5.8	5.9	6.2
24	4.9	4.9	5.0	5.0	5.1	5.2	5.2	5.3	5.3	5.4	5.4	5.4	5.5	5.6	5.7	6.1
25	4.9	4.9	5.0	5.0	5.1	5.1	5.2	5.2	5.2	5.3	5.4	5.4	5.5	5.6	5.7	6.0
26	4.8	4.9	4.9	5.0	5.0	5.1	5.1	5.2	5.2	5.2	5.3	5.3	5.4	5.5	5.6	5.9

Of still more interest are the records given, of the oxygen dissolved in the waters of New York harbor and vicinity, as summarized in Table 52.

Residual Oxygen.—Further treatment of the oxygen question follows closely the work of Messrs. Letts and Adeney in their British investigations. It speaks of 50 to 55 per cent. of the saturation point for oxygen as a limit below which it is unwise to go, partly on account of the danger of killing fish and partly on account of the necessity of maintaining a wide margin of safety against the exhaustion of oxygen, with its attendant odors of putrefaction. Here it may be remarked that these views are at variance with those described by the author in Chapter VIII and noted in the Thames and Elbe.

Reaeration.—Still further statements are made following Messrs. Letts and Adeney as to the absorption of oxygen from the air and giving it as 0.08 cubic centimeter per hour per liter for sea water and 0.03 for land water at ordinary summer temperatures.

For a water like that in New York harbor, containing about

TABLE 52.—AVERAGE AMOUNT OF DISSOLVED OXYGEN IN THE WATER DURING EBB AND FLOOD CURRENTS, JUNE 1 TO OCTOBER 5, 1909.

Location of samples	Tides					
	Ebb currents			Flood currents		
	Number of analyses	Cubic centimeters per litre	Per cent. of saturation	Number of analyses	Cubic centimeters per litre	Per cent. of saturation
Upper bay	42	36.0	64	24	4.91	78
Hudson river, below Spuyten Duyvil	29	3.67	66	68	4.63	76
Hudson river, above Spuyten Duyvil	10	5.13	83	22	5.01	84
East river, below Hell Gate	77	3.46	60	78	4.03	69
East river, Hell Gate to Long Island Sound	18	5.38	92	21	4.66	80
Long Island Sound, near Throgs Neck	3	5.90	100	5	5.78	98
Harlem river	30	3.28	56	22	3.21	55
Kill van Kull	40	4.49	78	24	4.76	82
Newark Bay	12	4.21	74	13	4.41	78
Passaic river at Newark	4	0.30	5	4	0.42	7
Arthur Kill	16	4.31	73	8	5.61	100
Narrows	17	4.16	74	15	5.18	92
Gravesend bay	.....	.....	.....	10	5.00	90
Lower bay	59	5.29	95	44	5.56	100
Rockaway inlet	6	5.10	93	6	6.14	100
Jamaica bay	18	4.06	73	11	4.26	81
Atlantic ocean, ten miles off Long Branch	.....	.....	.....	4	6.05	100
Gowanus canal	2	0.00	0	.....	.....	.....
Newtown Creek	.....	.....	.....	3	0.00	0
Wallabout canal	1	0.30	6	.....	.....	.....

Note.—In calculating the above averages, all the samples collected in the various sections were included, except that in the cases of Gravesend and Jamaica bays, those samples collected near sewer outlets were not used.

equal parts of sea water and land water, this figure may be taken as 0.055 cubic centimeter per hour per liter.

There was no striking difference between the dissolved oxygen content in the top and bottom waters, although some such differences were found in an irregular way. Reference is made again to the work of Messrs. Letts and Adeney in regard to the so-called gravitational streaming, whereby oxygen dissolved by water at the surface is moved rapidly downward throughout the depth of the water.

Passaic Valley Project.—Speaking of the influence of the proposed Passaic valley project, the Metropolitan Commission states that the waters of the upper bay and the Hudson river are at present heavily charged with sewage. The waters contain on ebb tides about 65 per cent. of the dissolved oxygen required for saturation while the average of ebb and flood tides shows about 71 per cent. From this it deduces, on the assumption that fish will not thrive in waters containing less than 50 per cent. of oxygen, that the waters of the upper bay and the Hudson river between Spuyten Duyvil and the Battery on ebb tides have a margin of safety of only one-third in excess of the amount necessary to support fish life. With the Passaic valley sewage added, equal to 0.1 the quantity of the total sewage of the district, it states that the safe margin of dissolved oxygen would be cut down with respect to fish life in the upper bay and Hudson river on ebb tides.

The Commission advised that after the United States Government withdrew as an intervenor the interests of the city of New York are such that it should make application to the United States Supreme Court for permission to intervene in the Passaic valley sewer case. This application was made, but it was denied by the Court.

Multiple Outlets.—As to the dispersion of sewage into the harbor through multiple outlets, as proposed by the Passaic valley project, the Metropolitan Sewerage Commission does not speak encouragingly. It intimates that at times of imperfect dispersion the dissolved oxygen would be reduced to so low a point as to lead to danger of putrefaction, with consequent evolution of foul odors. On pages 455–59 reference is made to tests indicating the difficulty in readily mixing warm and fresh water sewage with the colder saline harbor water. How far the objections can be offset by advantageously designed outlets to avail of the well-established velocities at the proposed dispersion area of the Passaic valley project is not shown. Nor is mention made of the time factor incident to the withdrawal of atmospheric oxygen from water as a result of bacterial decomposition.

Deposits near Shore.—Mention is made of so-called sewage traps or areas of reduced velocities which promote the deposition of suspended solids. Reference is made to the slips between the piers and to conditions where the sewers discharge not at the bulkhead, but at the pierhead line.

Salinity.—Numerous determinations were made of the per-

centage of land water and sea water respectively in the waters of New York harbor and vicinity. The tests were made by a salinometer provided especially for this work. A detailed description of the device is given by Mr. Kenneth Allen, Chief Engineer, in the *Journal of the Association of Engineering Societies*, Vol. XLVI, April, 1911, page 275. Briefly it consisted of a hydrometer with a thermometer in its center. Readings of the two were made almost simultaneously and the results reduced to an equivalent of the specific gravity readings at 60° Fahrenheit, in accordance with tests of standard solutions. The normal sea water was taken as containing 18,000 parts of chlorine per million parts of water, with a specific gravity of 1.025. The salinometers are graduated to differences corresponding to 360 parts of chlorine. Speaking generally, there was not a wide difference in the amount of land water in the samples taken from the surface, mid depth, and bottom waters. Naturally there was a difference found according to the stage of tide and the distance from the point of entrance of salt water into the upper harbor either from the East river or from the Narrows.

Table 53 shows a series of observations made on the last of the flood and the first of the ebb current of Dec. 14, 1909, in the Hudson river.

TABLE 53.—PERCENTAGE OF LAND WATER IN THE HUDSON RIVER FROM THE BATTERY TO TARRYTOWN, DEC. 14, 1909

Time	Location opposite	Depth in feet	Surface	Mid-depth	Bottom
10:00 a. m.....	Pier A.....	52	22	22	22
11:05 a. m.....	110th street.....	60	30	30	30
11:35 a. m.....	Fort Washington Point.	56	34	36	34
12:20 p. m.....	Mount St. Vincent.....	50	50	44	42
1:17 p. m.....	Hastings.....	50	60	52	50
1:35 p. m.....	Dobbs Ferry.....	50	66	58	56
2:30 p. m.....	Tarrytown Light.....	20	70	64	60

Condition of Harbor Bottom.—About 1100 samples were collected of mud from different places in New York harbor and neighboring waters. It is stated on page 425 that a large part of the bottom of the harbor was found to be polluted with deposits of solid matters from sewage. The Jersey flats west of a line from Constable Hook to Black Tom island were found to be singularly free of such deposits. In midstream the

bottoms of both the Hudson and East rivers were found to be fairly free of sewage deposits and generally so hard that samples were obtained with difficulty. The upper bay was generally polluted on its bottom with deposits, and the same is stated as to the lower bay, particularly in the principal ship channels. Foul deposits were frequently found in Kill Van Kull, Newark bay, and polluting deposits were found on the bottom near Manhattan island, the Jersey shore opposite Manhattan, and near the Long Island shore in the East river, at least to the pierhead line. The deepest deposits were found at the pierhead line opposite Elizabethport, Port Richmond, Hoboken, and at the mouth of Gowanus canal.

Digestion of Solids.—Quite an extended account is given of the way in which sewage matters are digested or hydrolyzed in the harbor, and on page 461 reference is made to various special tests indicating the rate of decomposition of organic matter in water at the Battery. Various organic solids decompose completely in three or four weeks. In comparatively pure water some tests indicated that organic matters remained almost intact.

Sanitary Aspects.—Another feature of interest that it is desired to mention is the possibility, according to a report by Mr. D. D. Jackson, that the health of communities resident in the vicinity of sewage-polluted waters may suffer from certain diseases transmitted through the agency of flies. Mention is also made of the possible influence of rats and vermin, particularly in connection with the bubonic plague.

Bathing in the waters of New York harbor is stated to be unsafe.

SUMMARY

The investigations led the Commission to summarize their work on pages 43–4 of their report of 1910, as follows:

Briefly stated, the Commission has found that the methods by which sewage is disposed of in the metropolitan district of New York and New Jersey call for immediate and far-reaching improvement.

The problem of disposing of the sewage of this metropolitan district has taken on a new aspect in recent years owing to the large increase of population which has occurred. The waters within 15 miles of Manhattan Island, which formerly were of ample capacity to receive and dispose of the sewage which was discharged into them, are rapidly becoming overburdened with the wastes.

DANGERS FROM BATHING AND FROM SHELLFISH

Bathing in New York harbor above the Narrows is dangerous to health, and the oyster industry, already driven to the outer limits of the district, must soon be entirely given up.

LOCAL NUISANCES

The Passaic river, the Rahway river, the Bronx river, Gowanus and Newton creeks, and the Harlem river have become little else than open sewers. Innumerable local nuisances exist along the waterfronts of New York and New Jersey where the sewage of the cities located about the harbor is discharged. Unless prevented by a proper system of regulation, these nuisances must inevitably increase with the increase in the quantity of sewage.

CONDITION OF WATER IN MAIN CHANNELS

Not only does the discharge of sewage now produce objectionable conditions near the points of outfall, but the water which flows in the main channels of the harbor above the Narrows and in the East and Hudson rivers is more polluted than considerations of public health and welfare should allow.

The studies made by this Commission show that the digestive capacity of this water for sewage is so reduced by pollution that restrictions should at once be placed upon the discharge of sewage therein to prevent the harbor from becoming positively offensive.

It has been proved that, contrary to popular belief, the tidal currents do not flush out the harbor satisfactorily, but cause the sewage to oscillate back and forth near its points of origin.

ADDITIONAL POLLUTION FROM TRUNK SEWERS

In addition to the objectionable conditions produced by the discharge of sewage from the cities surrounding the harbor, a number of extensive trunk sewerage projects have lately been constructed or designed to carry the sewage of inland municipalities for disposal into the waters in the immediate vicinity of the City of New York. These projects include the Joint Outlet Sewer of New Jersey, which drains an area of 37 square miles and discharges at Elizabethport opposite the Borough of Richmond; the Passaic valley sewerage project, which will drain 79 square miles and discharge at Robbins reef within a few hundred feet of New York city line, and the Bronx valley sewer, which will drain 35 square miles and discharge into the Hudson immediately above the New York city line.

These trunk sewers ultimately would add greatly to the polluting

matter entering the harbor. The total capacity of the works mentioned is seven hundred million gallons of sewage per day. By the time these sewers are running at their full capacity the quantity of sewage from the City of New York will be at least twice what it is today, or approximately, one thousand million gallons. It should be unnecessary to sound a clearer warning of the future condition of the harbor than these facts indicate.

TREATMENT WORKS

The Metropolitan Sewerage Commission was continued after making the report above mentioned in order to work out on general lines the procedure for the improved disposal of the sewage of Greater New York. In September, 1911, a preliminary report (see *Municipal Journal and Engineer*, Oct. 25, 1911, page 531) was made to which are attached several appendices of details. It is estimated that in 1940 the city of New York will have a population of nine million people and a mean dry-weather sewage flow of 1330 million gallons per day. The cost of installing central plants of different types is estimated as follows:

Discharge at sea on outgoing tide, with storage basins near Barren island, with outlet 5 miles from shore off Rockaway point	$140,600,000
Disposal on farm lands near Amityville, L. I., about 30 miles from New York City Hall, but excluding cost of about 175 square miles of land (to be treated at rate of 12,000 gallons per acre daily)	$152,780,000
Purification (intensive) at Barren island in Emscher tanks and sprinkling filters	$141,150,000

It is to be carefully borne in mind that these figures contain no allowance in any case for the expense of operation, maintenance nor depreciation of collecting works, pumping stations or disposal works.

The Commission reviews these subjects in the following terms:

Reviewing the various subjects dealt with in this report and combining the main facts and opinions for convenience of review, the following subjects seem to this Commission to be of special interest:

1. Although not necessary, it is within the range of engineering ability to collect all the sewage of the metropolitan district of New York and New Jersey to a central point for disposal.

2. The sewage of New Jersey, as well as that of New York, should be collected to a central point only in case the sewage is to be discharged

at sea continuously and not exposed upon or above the surface of the ground.

3. It would not be desirable, from engineering considerations and on account of the cost, to discharge continuously all the sewage of the New York and New Jersey metropolitan districts at sea, nor the sewage of New York at sea during all stages of tide.

4. The sewage of New York could be intermittently discharged at sea through tunnels, by employing storage basins and allowing the sewage to flow away on outgoing currents. The cost seems to make this plan prohibitive.

5. The sewage of New York could be carried to Long Island and disposed of on land, so far as engineering considerations are concerned, but the cost would not be justified.

6. The sewage of New York could be purified at one point so as to be inoffensive and without serious chance of harm to health. The works would cost what seems to be an excessively large amount of money.

7. The cost of collecting the sewage to one point and disposing of it intensively would be smaller than the cost of applying the sewage to land but it would still be so great as to make the project appear to be inadvisable.

8. At some remote time, it may be necessary to collect all the sewage of New York to a central point for treatment or discharge at sea. This fact should be kept in mind in laying out such systems of main drainage and treatment as may be necessary for the present and near future.

9. The plan of collecting all the sewage to a central point seems to be unnecessary for the reason that other remedies, costing less money and involving fewer engineering and sanitary difficulties, appear to be more suitable. These remedies lie in dividing the City of New York into districts, determined chiefly by natural drainage areas, and providing main sewers and proper methods of disposal for each. The boundaries of these districts and the way in which this Commission proposes to deal with them will be the subject of future reports.

REPORT OF COL. BLACK AND PROF. PHELPS

The Metropolitan Sewerage Commission is not the only body studying New York harbor in the interests of the state and city of New York. The chief engineers of the respective sewer systems of the five different boroughs of the city under the respective borough presidents give these matters attention as they are the ones in charge of construction and maintenance. By law the State Department of Health has some oversight in these matters, although its jurisdiction is perhaps made less clear since the

recent appointment of a state conservation commission organized on broad lines to handle a wide variety of subjects. In New York city there is also the Board of Estimate and Apportionment which takes active interest in these matters through the responsibility which they have in handling the finances of the city. This Board in November, 1909, appointed Messrs. Black and Phelps to advise concerning the location of sewer outlets and the discharge of sewage into New York harbor. They made several reports which appeared in the *City Record*, and which are brought together in a single volume with their final report which was presented to the Board of Estimate and Apportionment under date of Mar. 23, 1911. They summarized their interesting work in the following terms:

Summary.—The results of our investigations may be briefly summarized as follows:

1. The amount of dissolved oxygen in the harbor waters furnishes the most satisfactory criterion of the purity of these waters. We believe that this natural purifying agent should not be drawn upon to an extent which will reduce it below 70 per cent. of the full saturation value. This standard of purity refers not only to average conditions throughout the harbor and its tributaries, but also to average conditions within any of the sub-areas into which for the purposes of this study we have divided these waters.

2. We have shown that the circulation of water through these various sub-areas makes the condition of each dependent to a large extent upon the conditions in one or more of the others. We have determined these complex relationships with a reasonable degree of accuracy and in this way have been able to determine the most suitable points for sewage discharge and the probable effect of such discharge not only upon the area immediately adjacent, but upon the entire body of water under consideration. If the sewage of the entire drainage area tributary to these waters could be concentrated at the two entrances, namely, at the Narrows and at Throgs Neck, we estimate that the standard of purity laid down could be maintained, for the present at least, and for the immediate future until such a time that the population of this entire district has reached 7.4 millions. Such an arrangement would develop the fullest use of the natural purifying agencies. Any other system of discharge will result, even under present conditions of population in the production of local conditions below our proposed standard. That standard can be maintained at present by purifying the sewage which enters these waters at other points than those indicated to a degree which will reduce its oxygen requirements to one-third their present value.

3. The partial purification proposed in the last sentence will maintain our proposed standard of purity also in each of the several subareas considered, providing a proper system of discharge and dispersion be employed in each case. Under the present unsatisfactory method of discharge local nuisances are created and would continue to exist even after the purification which we have indicated has been established. These are due not to insufficient volumes of water as compared with the volume of sewage discharged, but to the fact that the fullest use of this water cannot be attained under existing conditions. In studying the sources of oxygen available for purification we have found that a serious misconception exists of the importance of reaeration by partially deaerated waters. We have determined that this reaeration factor is one that is without material significance in the case of the waters of New York harbor.

4. We have determined by experiments upon a practical scale made both at Brooklyn and at Boston, that a degree of putrescibility which will reduce the oxygen requirements of the sewage to one-third their present value during the summer months, can be obtained by a short period of septic treatment followed by forced aeration. The cost of such treatment will not exceed all told two dollars per million gallons, and further studies will doubtless make it possible to reduce this cost materially.

5. Our studies of main drainage schemes are included in four appendices to this report and summarized in Chapter IV herein. Separate schemes are submitted for the four drainage areas designated, Flushing, Corona, Jamaica and Richmond drainage areas, respectively.

These studies were necessary in order that feasible points of discharge might be located and they have been worked out only in detail sufficient to determine the feasibility of our proposed discharge points. While they have been made to conform as far as possible with existing and proposed works, they are in no sense offered as complete or final drainage plans. We have shown the most advantageous point of final discharge in each case and the feasibility of concentrating the drainage of the district at these points. If better lines and grades exist they can undoubtedly be found by a proper and thorough study of the situation.

The problems involved are of great magnitude and the importance to New York of their correct solution can hardly be exaggerated. In presenting this, their final report, the writers realize its incompleteness as regards some of the questions involved. They feel, however, that the lines they have followed are correct and that their studies will at least make more plain the path for further investigations.

Recommendations.—We recommend that further investigations be directed along the following lines:

1. The establishment of a standard of purity upon a firmer basis of fact than that which now exists. We realize fully that this standard

is the foundation stone of our work; we also realize that this whole matter is one upon which there are differences of opinion and that these opinions have but a slight satisfactory basis of observed facts. This is a matter which should be made the subject of the most thorough investigation possible, the results of which should be submitted to the impartial judgment of a commission of engineers for final settlement.

2. We further recommend in view of the favorable results of our experimental work, that the Twenty-sixth Ward Disposal Plant be equipped for the purification of the sewage now flowing through it by the process of aeration which we have developed in order that the merits and economy of this process may be more fully and finally determined. This project should in no sense be regarded as an experiment, since the process has already been carried through the experimental stage, and since, as we have shown, some purification of the sewage from this district will be required in the near future. At the same time the results obtained at this plant and the improvements in the process which will necessarily result from a careful study of the proposed plant, will be of immediate value in the solution of the final problem of disposal at other points throughout the Greater City.

3. Finally, we recommend a careful study of the whole matter of sewage discharge with reference to the proper dispersion of the sewage stream in the body of water into which it flows. Neglect of this matter is bound to result in serious local nuisances and will render it impossible to utilize to the point of fullest economy the natural purifying agencies which exist.

New Features.—This report contains many data on the circulation of water in the harbor and is a valuable contribution to the subject. Its general interest, however, relates to four matters, as follows:

1. The development of improved methods of measuring and recording the degree of stability or non-putrescibility of polluted waters as outlined in Chapter I, the full details of which should be studied by those having such problems in hand. (See *Engineering Record*, May 20, 1911, page 547; also *Municipal Journal and Engineer*, Aug. 16, 1911, page 199).

2. The recommendation for adoption of a method of aeration of settled sewage, as discussed in Chapter XXII.

3. The recommendation of a proposed standard of purity for harbor waters involving the existence at all places of an average of 70 per cent. of the dissolved oxygen required for saturation.

4. The discovery of some serious misconceptions in earlier literature as to the extent and importance of reaeration by partially deaerated salt waters.

STANDARD OF 70 PER CENT. OXYGEN

This standard is based upon their statement on page 17 that the first indication of pollution is the disappearance of major fish life, for the existence of which 70 per cent. of the saturation volume of oxygen is necessary. The report states that other forms of fish life can exist until a limit of 30 per cent. has been reached. Bnt it adds that when the remaining volume of dissolved oxygen in a stream falls below 50 per cent., the stream may at times become turbid and noisome during hot weather. It refers to the Passaic river in the vicinity of the Pennsylvania railroad bridge, which Messrs. Black and Phelps found to constitute a nuisance during the summer season when the oxygen was reduced below 30 per cent. It does not explain how far the organic content and resulting decomposition relate to flowing sewage in the Passaic river and how far to deposits that were probably putrefying upon the stream bed.

It adds further data as to the dissolved oxygen content of the Hudson river opposite Mount St. Vincent near the Yonkers city line. A series of 42 samples were taken during a period covering nearly 12 hours. The percentage of sea water was found to vary from 40.5 to 55.5, with an average of 42.2. The dissolved oxygen was found to vary from 39.6 to 66.8 per cent. of the saturation value with an average of 51.2 per cent. These data were obtained by Prof. Phelps in September, 1910.

Speaking generally, this proposed standard of Messrs. Black and Phelps seems to have been received by those familiar with this general line of work as radical and needlessly severe. It does not take long to learn that it is based, as above stated, upon certain information with respect to the requirements of major fish life. It differs from the information secured by American engineers at London and Hamburg where no particular difficulty seems to have been encountered when the oxygen values have fallen to 30 and occasionally 20 per cent. Reference is here made to pages 217 and 302 and conclusions of the 1911 report of Mr. Wisner, of Chicago.

REAERATION

Careful tests and formulas led to diagrams which indicate the extent and rapidity of the diffusion of atmospheric oxygen from the surface into the lower depths of a body of water. The

studies were based upon the diffusion or reaeration of fresh water, and data were secured which are indicated in the following table:

TABLE 54.—AMOUNT OF OXYGEN ABSORBED FROM THE ATMOSPHERE BY A QUIESCENT BODY OF FRESH WATER AT 20° C. DURING STATED PERIODS OF TIME, AT STATED DEPTHS AND WITH STATED INITIAL CONCENTRATION; EXPRESSED IN POUNDS PER MILLION GALLONS

Initial concentration. Per cent. saturation	Time in hours					
	1	6	10	12	20	24
Depth 5 feet.						
0	0.636	1.66	2.14	2.34	3.00	3.41
10	0.566	1.49	1.93	2.10	2.70	3.06
30	0.444	1.16	1.50	1.64	2.09	2.39
50	0.322	0.827	1.07	1.16	1.50	1.68
70	0.193	0.497	0.643	0.704	0.904	1.03
90	0.064	0.166	0.214	0.234	0.300	0.341
100	0.00	0.00	0.00	0.00	0.00	0.00
Depth 10 feet.						
0	0.229	0.804	1.11	1.17	1.51	1.66
10	0.207	0.720	0.995	1.06	1.36	1.49
30	0.161	0.566	0.781	0.820	1.06	1.16
50	0.115	0.398	0.551	0.581	0.750	0.827
70	0.069	0.245	0.331	0.352	0.452	0.497
90	0.023	0.080	0.111	0.12	0.151	0.166
100	0.00	0.00	0.00	0.00	0.00	0.00
Depth 15 feet.						
0	0.115	0.459	0.666	0.735	0.996	1.11
10	0.107	0.413	0.597	0.658	0.896	0.995
30	0.077	0.322	0.467	0.513	0.696	0.781
50	0.061	0.230	0.337	0.367	0.497	0.551
70	0.031	0.138	0.199	0.222	0.299	0.337
90	0.012	0.046	0.067	0.074	0.100	0.111
100	0.00	0.00	0.00	0.00	0.00	0.00
Depth 20 feet.						
0	0.077	0.306	0.436	0.513	0.712	0.804
10	0.069	0.276	0.390	0.459	0.643	0.721
30	0.054	0.214	0.306	0.360	0.497	0.566
50	0.038	0.153	0.214	0.260	0.352	0.398
70	0.023	0.092	0.130	0.153	0.214	0.245
90	0.008	0.031	0.044	0.051	0.071	0.080
100	0.00	0.00	0.00	0.00	0.00	0.00

As to salt water, it is stated that the diffusion coefficient is reduced by viscosity and the reaeration or diffusion is not greater, but probably less, in salt water than in fresh water. This seems to be contrary to certain deductions of Dr. Adeney.

STREAMING EFFECT

On the question of the "streaming effect," whereby in the case of salt water the oxygen has been stated to be distributed more evenly through a depth of water than in the case of fresh water, the report is particularly interesting. There is a tendency toward accumulation of oxygen near the surface of all water, due to absorption from the atmosphere. It is stated that Dr. Adeney found the streaming effect always present when salt water was used in tests, but most markedly so when a jet of air was introduced just below the surface of the water. Prof. Phelps finds that this is due to the evaporation of the top layer of the solution, thus leaving a slightly denser solution on top, which promptly descends. If the experiment is made with air which has become saturated with moisture so that evaporation no longer takes place, this streaming effect disappears because, when the air is saturated with moisture, evaporation no longer takes place. On the other hand, if the air is first dried, the streaming effect is restored and on a more vigorous basis than before, as shown by the passage of coloring matters from the surface down into the lower portion of the body of water.

The effect of wind action, moving vessels, and tidal movements are all discussed. They seem to be of comparatively minor consequence as compared with the saturation which takes place at the top of any body of water exposed to the air. Below the surface the amount of oxygen received from the atmosphere depends upon the rate of diffusion. The other factors are a function of the effect of mixing, but while they are of importance they do not stand out conspicuously in comparison with the effect of diffusion. The details cited are well worth careful study.

GENERAL PRINCIPLES OF DIFFUSION

On this question of diffusion there are, of course, physical laws indicating the tendency of gases in liquids to pass from a zone of maximum concentration to locations of less concentration. In the case of oxygen the co-efficient of absorption, or amount of gas held by a given volume of water, decreases as the tempera-

ture increases, but increases as the pressure becomes higher. This is all explained by Messrs. Black and Phelps.

Light upon the question is thrown in a note to the editor of *Science*, published on Aug. 25, 1911, by Prof. Carl Hering, of Philadelphia, as follows:

The question has often been asked, how does the air, which is assumed to be necessary for the life of deep-sea fishes, get to those depths? Possibly a satisfactory explanation exists; if not, the following suggested itself to me as a plausible one, and possibly as a new one.

It is well known that the amount of gas which a liquid will hold in clear and stable solution increases with the pressure. The liquid in a bottle of champagne or in a siphon bottle, for instance, is clear until the pressure is released. It may be assumed that the water on the top surface of the ocean is being continuously saturated with air due to the spraying of the waves. The layer beneath is at a slightly higher pressure, hence will hold more air per unit volume than the one above it. Under such circumstances it seems that there should be a tendency for the air in the top layer to move down to the less saturated one beneath it, until it too is saturated, and this will require a larger amount of air per unit volume. The same is true of the next lower layer, and so on to the bottom.

It would seem to follow, therefore, that air actually descends into the ocean depths, and if it is being consumed there for oxidation and nitrification purposes, there should be a continuous flow of air downward into the deepest ocean waters. If oxygen dissolves in sea water more freely than nitrogen, the deep-sea fishes should be enjoying richer air and therefore should require less of it than those living nearer to the surface.

The above statement has brought out further discussions in *Science*, particularly from Prof. P. F. Evans, in the issue of Oct. 27, 1911, and Mr. G. W. Littlehales, in the issue of Dec. 22, 1911. The former speaks of the pressure to which the solubility of oxygen is proportional as that of the partial gas pressure of oxygen; and that the great pressure in ocean depths is hydrostatic and has but very slight effect upon the solubility of gas. He explains that the content of oxygen in lower depths is a matter of diffusion. Mr. Littlehales, however, while speaking of the effect of hydrostatic pressure, mentions the possibility of the gas content in bottom waters being greater than in surface waters on account of the lower temperature prevailing in the depths of the ocean. In this way he accounts for the opportunity of oxygen to pass to lower depths in comparatively high proportions.

It is of interest to note in this connection that Messrs. Birge and Juday in their Wisconsin report of 1911 on pages 59–63 speak rather disparagingly as to the evidence of high oxygen content in bottom depths of various lakes and seas. It is stated that Hüfner, in speaking of the ineffectiveness of diffusion, calculates that if the [redacted], which is about 820 feet deep, should lose its supply of oxygen and then acquire a new supply from the air by diffusion alone, it would require over a million years for the entire body of water to become saturated with this gas. Further evidence is cited as indicative of decreasing oxygen content with increasing depths, particularly in bodies of salt water. In Lake Geneva, however, the oxygen content was not so deficient. In the Black and Caspian seas, in certain marine investigations and in the Norwegian fjords the lower strata of water are low in oxygen content, if indeed this gas is not absent. As the oxygen content in the deeper waters diminishes there seems to be a correlated decrease in living organisms.

GOWANUS FLUSHING TUNNEL

For many years Gowanus canal and bay have been one of the most polluted arms of New York harbor. Gradually there has been removed the dry-weather sewage flow of a large portion of Brooklyn which hitherto drained into this waterway. Storm-water overflows and some industrial wastes, particularly those from gas works, are understood still to be a factor. As described in the *Engineering Record* of Jan. 11, 1908, and Aug. 19, 1911, as well as in *Engineering News* of June 29, 1911, a brick tunnel, some 6280 feet long and 12 feet in diameter, has recently been completed and into which from the upper end of Gowanus canal some 500 cubic feet per second of water is discharged by propellor pumps into Buttermilk channel at the outlet of the flushing tunnel at the foot of DeGraw street. While this project has been in service too short a time to make definite comments upon it, it may be mentioned that the clearing of the surface water has not brought to an end the ebullition of gas from the decomposing sludge deposits upon the bottom of the canal. Indeed, that would not be a likely result for some time to come, even if the overlying water were pure distilled water saturated with oxygen.

THE NEW BEDFORD DISPOSAL PROJECT

In June, 1911, Messrs. Metcalf and Eddy made a report on the disposal of sewage for the city of New Bedford, located upon Buzzards bay, in Massachusetts. Considerable pollution of the immediate harbor has taken place for years, owing to the lack of proper dispersion of the sewage which is discharged at the head of the slips and not at the end of the piers. Independently of the question of the pollution of the slips, difficulties have also developed as a result of discharging sewage into shallow tidal estuaries which have considerable areas of flats exposed at each ebb tide. The local relation to shellfish is of significance, and according to data prepared by Mr. William F. Williams, City Engineer, the following table is given by Messrs. Metcalf and Eddy:

TABLE 55.—TYPHOID FEVER AT NEW BEDFORD, MASS.

Year	Population	Actual		Per 100,000 population	
		Cases	Deaths	Cases	Deaths
1900	62,442*	132	22	212	35
1901	64,000	99	19	155	30
1902	69,000	181	24	262	35
1903	71,000	153	28	216	39
1904	71,500	64	12	90	17
1905	74,362*	56	4	75	5
1906	79,000	57	7	72	9
1907	85,000	102	10	120	12
1908	86,000	98	20	114	23
1909	96,500	12	20	130	21
1910	96,652*	.....	.....	.....	.....

* Actual population by State census.

It is stated that during the four-year period from 1900 to 1903, inclusive, when there were no restrictions upon the taking of shellfish, the typhoid death rate was approximately 35. For something more than two years, beginning during the year 1904, the taking of shellfish from polluted water was prohibted and rigidly enforced. This was followed by lax enforcement, with

increases in the typhoid rate due, it is thought, in a considerable measure, to shellfish infection.

Reference is also made to the danger of bathing in these sewage-polluted waters.

The proposed works are to comprise grit and screen chambers and a 60-inch cast-iron outfall pipe extending 3000 feet into Buzzards bay, discharging at a depth of about 30 feet through 20 or more orifices in the pipe.

Float observations were made near the proposed points of sewage discharge, and it was found that the average velocity was a little more than one-fourth mile per hour, with a range from a minimum of one-twelfth to maximum of one-half mile per hour. It is stated that these observations are favorable to rapid distribution of the sewage in the waters of the bay.

The sewage of this city, about 100,000 population, may also receive hypochlorite treatment. Messrs. Metcalf and Eddy scarcely think it is necessary, in view of the conditions of tide, wind and water in Buzzards bay and the remoteness of the proposed distribution area from shellfish grounds and bathing beaches. Reference is also made to the impracticability of sterilizing the mixed storm water and sewage flow from these combined sewers at times of heavy rainfall and the impossibility of controlling sanitary conditions within the harbor so as to make it safe to bathe within the harbor or to eat the shellfish taken therefrom.

Profs. Sedgwick and Phelps reported strongly in favor of hypochlorite treatment, which if adopted Messrs. Metcalf and Eddy advise to be applied to settled sewage rather than screened sewage, on account of greater efficiency with the former.

LOS ANGELES, CAL.

Years ago broad irrigation or sewage farming was abandoned as a means of disposal of the sewage of Los Angeles, California. The reason of this is to be found in the extraordinarly rapid growth of this city and its suburbs, which caused real estate owners to subdivide their holdings into house lots and to object to the odors from sewage farms located in the general vicinity of lands to be developed. For some years Los Angeles has discharged its sewage through an outfall sewer terminating in the Pacific ocean 942 feet from shore. Its submerged end is 6 feet below

mean sea level at a place where the water is about 16 feet deep.

The sewage is discharged through a single outlet without any form of treatment whatever. Some floating matters become stranded along the beach a few hundred yards from the outfall. There is also some odor noticeable at times to the passengers of the electric railroad which runs along the shore. The city of Los Angeles, however, owns the land for one-half mile on either side of the outfall sewer, and consequently no buildings are permitted within this distance. This outfall sewer

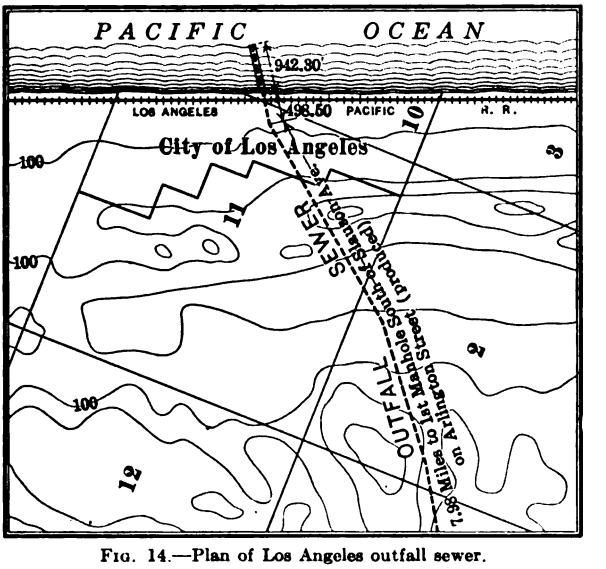


FIG. 14.—Plan of Los Angeles outfall sewer.

is some 8 miles long from the outskirts of the city, following recent annexations. It is built of brick and concrete, and as stated in Chapter I some difficulties have been experienced with the disintegration of cement and brick due to the formation of hydrogen sulphide. The outfall is a 34-inch creosoted wood stave pipe terminating in a riveted steel drop pipe 40 inches in diameter. It is supported on a timber pier built especially for the purpose. At mean sea level the wate) line is about 150 feet from the concrete pier on shore where the wooden trestle or pier commences. There is a 24-inch steel bypass pipe which extends some 200 feet from the concrete pier, or 50 feet beyond the water line at mean sea level.

Mr. Willis T. Knowlton, Engineer of Sewers for the city of Los Angeles, has aided in the preparation of the above statement and furnished official drawings from which have been prepared Fig. 14, showing the general location of the outfall sewer, and also Fig. 15, indicating the details of the outlet into the Pacific ocean.

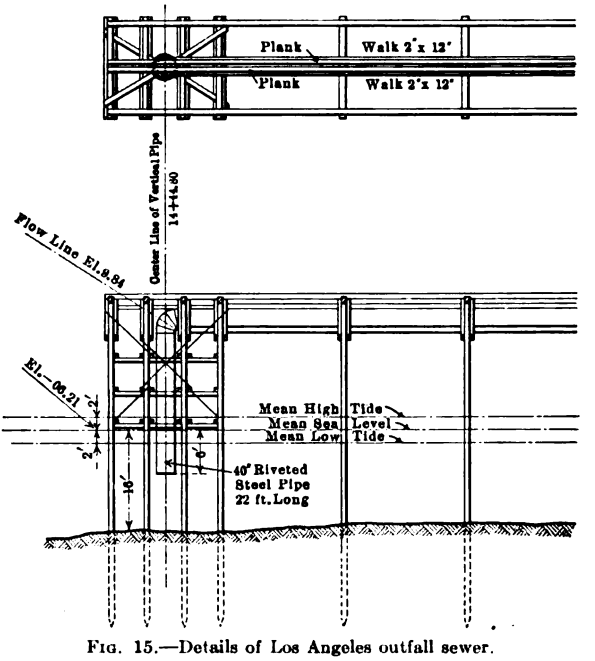


FIG. 15.—Details of Los Angeles outfall sewer.

CHAPTER XI

SEWAGE TREATMENT WORKS

The disposal of sewage by treatment in works of artificial construction becomes necessary in some cases through the failure of the dilution method to meet local requirements. Such works vary widely in their cost, efficiency and style of arrangement. Naturally this is so, as they have to meet widely varying conditions of service. As the demand for sewage treatment has increased in recent years there has been a more or less corresponding increase in the available methods of treatment, all aimed at giving satisfactory results at the minimum expense.

The scope of treatment works will be explained briefly in this chapter to serve as an introduction to the remainder of this book, which contains a description of the more important devices found in practice for the treatment of sewage.

OBJECTS SOUGHT

To appreciate the scope of sewage works it is necessary to keep clearly in mind the several items wherein, as explained in Chapters VIII to X, the dilution method of sewage disposal fails under some circumstances. These shortcomings have caused increasing attention to be given to the removal from raw sewage of the following:

1. Floating matters.
2. Settling matters.
3. Non-settling putrescible matters.
4. Objectionable bacteria.

The entrance of trade wastes into sewers should be restricted to certain reasonable limits, so that the treatment of the resulting mixture may come within the scope here stated. All the treatment that is needed at some places is the removal of floating matters and the dispersion of the sewage in a large deep body of water with favorable velocities of flow. As previously stated, the city of New Orleans satisfactorily avails of such a method in the disposal of its sewage into the lower Mississippi river.

Dilution in some instances provides ample treatment except for floating matters and the accumulation of sludge banks which putrefy and give off objectionable gases and odors of decomposition. Sludge deposits also remove more oxygen from the overlying water than has been realized until recently. In such cases it is necessary to remove from the sewage both the floating and the settling solids.

It is easy enough to do this in settling basins aided by screens. But the economical and inoffensive disposition of the resultant deposit or sludge has been and still is one of the principal problems of this branch of engineering. Happily the careful use of septicization now allows the sludge question to be handled satisfactorily.

Some streams are so small that there is not sufficient oxygen available in the waters to insure aerobic decomposition of the putrescible sewage matters and to leave sufficient oxygen for the protection of fish life. In such instances it is necessary to remove from the sewage some or all of the putrescible matters, so that the treated product will be stable or non-putrescible. This result must be secured for some effluents when undiluted with any water. This means an oxidizing treatment, ordinarily secured in some kind of filter.

Objectionable bacteria sometimes require removal in connection with shellfish layings, or where a public water supply is drawn from the body of water into which the effluent is discharged. Bathing requirements also call sometimes for this treatment. Until quite recently disease germs have been removed by sand filtration. Now sterilization by hypochlorite treatment is available at less cost.

Coarse-grained filters have pressed strongly for attention during the past few years through their ability to produce a stable effluent at comparatively small cost. When combined with sedimentation and sterilization they produce satisfactory results for many projects.

Some problems require for their solution the elimination from sewage of all four of the groups of constituents which are mentioned above. This has led to the expression "sewage purification" works. There are so many instances, however, where satisfactory results may be obtained with partial purification that the term "sewage treatment" has naturally and properly come into use.

METHODS OF TREATMENT

Having made it plain that there are various kinds of sewage disposal problems, it is now necessary to note in outline the methods by which satisfactory results may be obtained.

There are different ways of securing an approximately equal degree of purification of sewage. Within certain limits a choice of methods may be made, depending upon the cost under varying local conditions. This will be more apparent upon reading the final chapter containing a comparative summary of what may be accomplished with the several methods of treatment. We will briefly outline now the scope of the principal devices receiving attention at present with respect to the four groups of sewage matters as above mentioned. Reference to the Table of Contents will probably aid the reader.

Screens.—Coarse or medium-sized screens have generally been used in this country to protect pumps from clogging. There has been comparatively little effort made to use screens for the removal of suspended matters from sewage which otherwise could be disposed of satisfactorily by dilution.

Fine screens are not utilized in this country to as great an extent as in Europe. Increased attention is being given to them, not only for securing improved conditions along large rivers that receive untreated sewage, but also in connection with filters, in order to minimize the cost of operation due to the clogging of filtering material.

Screens with a mesh of about 40 openings per lineal inch have been recently installed at several places. They deal not only with floating matters, but also with a portion of the settling solids. They do not remove much if any of the unstable matters, although they are of more aid than has been generally considered, because the depositing solids in time decompose so as to consume oxygen and thus become a factor in the oxygen balance.

Sedimentation.—Basins, in which the velocity of flow is reduced, permit the settling solids to be deposited so that there is a clarification of the effluent leaving such tanks. The remaining solids on the bottom of the basin or tank are generally spoken of as "sludge." Disposal of sludge has been bothersome and expensive and has served to retard seriously the progress in the installation of these clarifying devices.

With small installations floating matters may be removed

from settling devices at frequent intervals with considerable success. For large installations screens are usually employed in conjunction with sedimentation tanks.

Sedimentation tanks cause some improvement in the stability of the sewage and in the removal of objectionable bacteria. They are only a step, however, in the direction of securing an effluent which will not putrefy or transmit disease. In many cases they should be used in conjunction with other devices or where conditions are favorable for availing of the benefits of the dilution method. Their usefulness is of wider scope than is credited to them by many sanitarians, especially as to the elimination of sludge banks in rivers and harbors.

Chemical Precipitation.—Certain chemicals will coagulate fine matters so that they may be deposited in settling tanks instead of passing out with the effluent.

Septicization.—This is essentially a biological process of liquefying and gasifying sludge so that the humified residue may be disposed of without offense as to odors.

Strainers, Roughing Filters, Slate Beds, etc.—This group of devices affords a generally similar treatment to that obtained by sedimentation. They deal with clarification along physical lines and not the reduction of organic matter and bacteria along chemical and biological lines.

Filtration.—This expression is now generally applied to beds of sand, stone, clinker or other material, which will not disintegrate readily, and to which sewage is applied under conditions where the aerobic decomposition of organic matter, with the aid of oxygen, bacteria and other forms of life, produces a stable non-putrescible effluent.

The rate of filtration per cubic yard or square yard of material varies tremendously with the size of material, as does the cost and efficiency of the treatment. With the coarser materials the purification and clarification are such as to require some other treatment in some cases.

Sand filters under favorable conditions provide satisfactory clarification and removal of bacteria, as well as a non-putrescible effluent. The latter, however, is the chief characteristic of the high-rate contact beds and sprinkling filters of coarse material.

Sterilization.—By the use of certain chemicals, such as hypochlorites or ozone, it is feasible to destroy objectionable bacteria without going to the expense of filtration. Even screening or

sedimentation is not necessary for the application of a sterilizing process, although usually one or both of these arrangements is a feature of such plants.

Combinations and Modifications.—Enough has probably been said to show how varying sewage problems are solved by different forms of treatment according to local needs and conditions.

The above outline by no means indicates the full story of what can be done with the different groups of purification devices. Various combinations of these and other arrangements will be described, as shown in the Table of Contents.

Emphasis is again given to the individuality of problems both with respect to the kind of treatment needed and the variations in the way in which the solution may be secured. Expense is an important item. The day has gone by when the dilution method without any treatment whatever can be considered satisfactory for the great majority of problems. On the other hand, full purification is not needed in many cases. Each project should receive the cheapest method of treatment that will regularly give adequately suitable results.

CHAPTER XII

SCREENING

Screens in one form or another are in use at a majority of plants where sewage is pumped or purified. The purpose of screens varies with different installations and the styles of arrangements differ accordingly.

Screens are installed in some instances to protect pumps from injury, and in other cases to prevent comparatively coarse matters from forming either scum or sludge banks in bodies of water in which the sewage is dispersed. Screens are also used for the removal of scum and gas-lifted sludge from the effluent of septic tanks or settling basins, so as to reduce the clogging of sand filters or sprinkling filters.

Utility.—The utility of screens is based on the assumption that certain suspended matters may be removed more advantageously and economically in this than other ways.

American practice in the utilization of screening is not so far advanced as is the case in Europe. Not only is there much room for improvement in this country, generally speaking, but views are not clearly crystallized as to where the economical limit in the use of screens is to be found.

With varying local conditions there are naturally found different solutions for the problem as to how far screening should be carried for the removal of suspended matters. Obviously it makes a difference whether ample head is available for the operation of screens, whether or not the sewage is subsequently to pass through sedimentation or septic tanks, and whether it finally is to be applied to filters, particularly those of the sprinkling type to which the liquid is applied through sprinkler nozzles of small size that are liable to clog.

Fairly large pumps of the centrifugal type, 8-inch pumps or larger, are seldom bothered by matters that are removed by screens. Clogging is a serious matter with small pumps of this type, with their still smaller waterways, unless the sewage is carefully screened. The cost of such screening is then considered in comparison with other procedures. One is to store

the sewage in receiving tanks of a size to facilitate the use for short intervals of such pumps of fairly large size.

Compressed air ejectors are used for lifting sewage to small heights when the volume is small, say 100 gallons per minute on account of freedom from clogging. They are wasteful of power and the cost of operating the air ejectors is more than that of centrifugal pumps. Their wide use in office buildings for lifting sewage from sub-basements to street sewers, and for other purposes, is explained by this freedom from clogging; and the opinion that it is cheaper to so waste power rather than go to the expense of efficient screening.

Reciprocating pumps ordinarily require the sewage to be screened, depending upon the type of valve used in the water cylinder. These valves are liable to remain "unseated," due to solid matters becoming lodged in the valve seat. Consequently the sewage to some extent is forced back through the suction pipe and both power and capacity are wasted as a result of this "slip."

There is a growing tendency in this country to make more and better use of screens. The influence of local conditions is so great, however, that we shall not attempt to lay down any rules or general customs as to procedure. We shall simply indicate current practice with especial reference to some of the newer installations and discuss briefly their merits and demerits. Comparatively old installations in this country do not ordinarily afford a satisfactory criterion as to present tendencies in the direction of self-cleansing fine screens. To some extent this applies also to medium-sized screens which are cleaned by hand.

KINDS OF SCREENS

For convenience screening arrangements may be divided into three classes, more or less arbitrarily, as follows:

1. **Coarse Gratings.**—These are bars or posts set with clear openings of from 2 to 6 inches and ordinarily are employed in connection with pumping stations to protect pumps from injury by relatively coarse debris which may enter the sewers through manholes or elsewhere due to carelessness or maliciousness. They have very little influence on the clarification of the sewage, and we shall not go into details concerning them.

2. **Medium-sized Bar Screens.**—These usually have a clear space of from perhaps 0.5 to 2.0 inches. They are in quite gen-

eral use in this country, arranged in various combinations. Frequently two sets of screens are used, in addition to coarse gratings. In some instances, as at Columbus, Ohio, the intermediate set has a clear space of 1 inch and the finest of the set of three a space of 0.5 inch in the clear. At the pumping station of the South District of the Metropolitan Sewerage Works at Boston, Mass., there are double screens of the same size placed about 1 inch apart with the rods in one opposite the clear space of the other. This gives an opening of 0.125 inch in the direction of the sewage flow with a diagonal opening of about 1 inch.

3. **Fine Screens.**—These are bar screens with openings less than 0.5 inch or else screens of fine metal cloth. There are comparatively few of the former in America. At Washington, Pa., there are two sets with openings of 0.375 and 0.25 inch, respectively. Temporarily, in order to reduce the clogging of sprinkler nozzles, screens of 0.25-inch mesh have been used at Columbus to free the septic tank effluent of gas-lifted sludge particles. Most of the experience with fine screens in this country is confined to the Weand "segregator" which is a revolving mechanically-cleaned screen made of wire cloth with about 36 meshes per lineal inch. Such an arrangement has been in use since January, 1908, at Reading, Pa., and a similar device with some mechanical improvements was installed in Brockton, Mass., early in 1911. Others are being built at Atlanta and Baltimore to remove suspended particles from settled sewage before application to sprinkling filters. It is said that the Reading rotary screen has been recommended for adoption at New Brunswick and Atlantic City, N. J.; Lynn, Mass.; and some other places.

At New Brunswick screens of this type were recommended by Messrs. Hering & Fuller in December, 1910, in conjunction with sterilization devices to secure protection of shellfish layings in Raritan bay. Of three proposed gravity outlets, one on the outskirts of the city is to have Imhoff tanks and two along the thickly built-up river front are to have fine screens with the screenings disposed of by incineration.

Screens with a clear space of not more than 0.4 inch have been recommended for the Passaic Valley trunk sewer plant and also at Vincennes, Ind.

The economic usefulness of these devices refers more to large than to small installations, and is related also to the availability of attendants who devote themselves to other duties. For certain

very large projects Mr. Wisner, on page 25 of his report of 1911, speaks disparagingly of decreasing putrescible matters in this way at Chicago.

EFFICIENCY OF SCREENING

Screens are used essentially for purposes other than the removal of putrescible organic matters. Experiments at Reading, Pa., with the Weand segregator showed that there were removed from 15 to 20 per cent. of the total suspended matter in the Reading sewage. Perhaps half of this was organic matter. Locally there was more than ordinary reason for using such a device, due to the finely divided particles in the sewage caused by wastes from felt hat factories.

The comparatively coarse matters removed by screens make but a small difference in the putrescibilty or instability of sewage before and after treatment. In fact, in Mr. Wisner's Chicago report it is stated on page 25 that there is little or no improvement in the stability of the local sewage due to screening through a device with 40 meshes to the inch. On the other hand, as has been pointed out already, the clarification due to screening decreases sludge banks and the deoxygenation of water overlying such decomposing deposits.

If fine screens could be used at each individual household for the removal of suspended matters, the efficiency of these devices would be considerably increased above what is found in practice. Sewage becomes comminuted as it flows through the sewers, and the older a sewage is the more difficult it is to clarify it in this way.

The degree of dilution or strength of the sewage is also a factor. The more dilute a sewage is the more difficult it becomes to clarify it when the results are expressed by weight of dry matter per thousand population connected with the sewers. The influence of varying age and dilution makes it difficult to utilize satisfactorily the results of screening experiences in Europe as a guide for American practice.

The removal of bacteria by screening is so small as to be negligible.

MEDIUM-SIZED SCREENS

Bar screens with from 0.5- to 0.75-inch openings show a removal ranging from about 0.5 to 10.0 cubic feet per million

gallons of sewage. The results vary with the strength, kind and age of the sewage. The majority of results seem to fall within a range of from about 4 to 8 cubic feet per million gallons. We will speak of the screens at Plainfield, N. J., as illustrative of some of the factors to be taken into consideration and the results that may be expected from devices of this sort.

PLAINFIELD SCREENS

The screens at this plant will be described in some little detail, owing to our familiarity with the results secured by Mr. Lanphear, the chemist in charge of the works. The volume of sewage flow averages about two million gallons daily, the quantities frequently ranging from about 10 per cent. below to about 10 per cent. above the average, depending on the ground water entering the system of separate sewers. During severely cold weather the custom of allowing water faucets to remain open may cause the flow to reach 25 per cent. above the average. The average flow of the sewage is a little less than 100 gallons per capita daily. The outfall sewer is a 24-inch pipe laid at a slope of 1 to 1200. The water supply is from underground sources and fairly hard. The sewage is fresh and but slightly comminuted as it reaches the screen chamber within the city limits.

Several screening devices have been tried and at intervals the use of screens has been omitted altogether. For several years the screens have been operated regularly with a view to reducing the amount of floating matter entering the septic tank and forming a thick scum on the surface.

Arrangements.—In 1908 the present screen was installed in the original screen chamber, which is in two compartments each 5 feet by 8 feet. Originally there were horizontal screens through which the sewage flowed upward. The clogging of these screens and inability to remove the screenings through a blowoff pipe at the bottom of the compartment caused their abandonment.

The present screen is 8 by 5 feet and of wrought-iron bars 1.0 by 0.25 inch, spaced 0.5 inch apart in the clear. It is set so that it forms an angle of about 30 degrees with the horizontal and its top is about 1 foot above the top of the entering sewer. As the screen becomes clogged the water-level rises on the upstream side until it reaches about 6 inches above the top of the sewer. Then it is cleaned.

Cleaning Procedures.—The screens are ordinarily cleaned about 10 or 12 times during a 24-hour period. The interval ranges from about 90 minutes at mid day to about 4 hours late at night. The time occupied per 24 hours in attending to the screens aggregates about 5 hours. This includes the time required for carting the screenings in a wheelbarrow to a trench in which they are buried, and also the digging of the trench and the covering of the screenings. The latter are covered with dirt once a week or oftener, except in winter, when freezing weather may interfere temporarily with the schedule. In the autumn care is taken to see that sufficient trench capacity is provided to last until spring.

Area.—With these inclined bar screens of a clear space of 0.5 inch it may be stated that there is a width of 3.2 inches and an area of 2.2. square feet per 1000 population. If the clear space were smaller, the screening surface should be increased accordingly.

Screenings.—At Plainfield these average about 5.7 cubic feet per million gallons of sewage. They are largely waste paper and fecal matters, with practically no garbage. The screenings as removed weigh about 46 pounds per cubic foot, with about 84 per cent. of water. As they remain upon the floor, free water drains out to the extent of over 10 per cent., so that the drained screenings weigh about 35 pounds per cubic foot.

Screen Chamber Deposits.—Undoubtedly there are deposits formed in the screen chamber above the screen prior to cleaning. When the screen is cleaned, however, the velocity of flow increases from a minimum of about 0.2 foot per second to about 2.3 feet The latter seems to be sufficient to remove the accumulated deposits both in the sewer and screen chamber. No ebullition of gas has been noticed in the screen chamber, which has been cleaned but once in the last three years.

Local Records of Cost.—The local records at Plainfield give the cost of screening as $0.50 per million gallons of sewage. This does not mean a great deal as a general cost figure, owing to the influence of local conditions. The screen attendants have to travel some 800 or 900 feet from the middle of the contact filters to the screen house. Much of the time is therefore occupied in traveling to the screen house, which was originally built for use with abandoned intermittent sand filters. Furthermore, the cost of screening varies much with the other duties which the attendants have to perform and the allotment of time for

each specific purpose. The cost is also influenced by the rate of wages and the capacity of the plant and the manner of disposing of the screenings.

MECHANICAL APPLIANCES

For plants of a fairly small size, say five million gallons daily flow or less, there has not been much disposition in America to use other than hand-cleaning arrangements, more or less after the order of the Plainfield works.

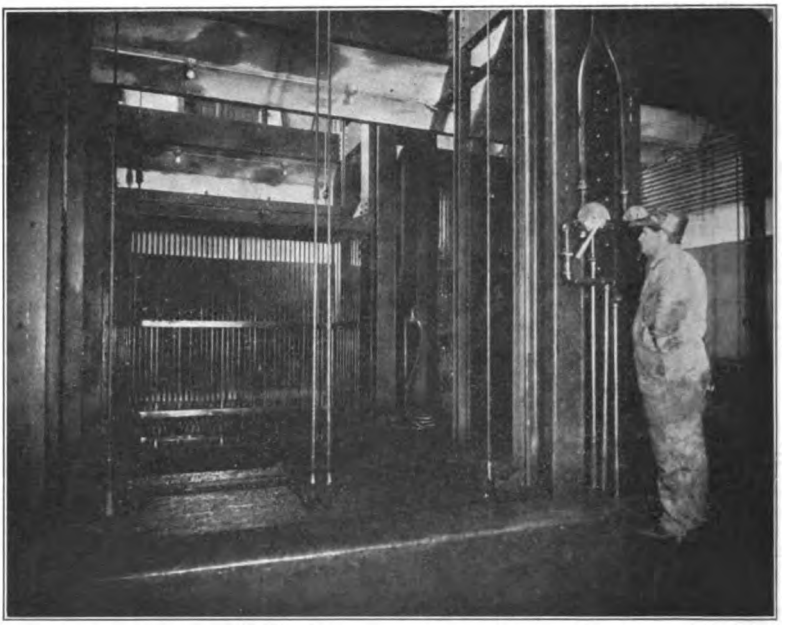


FIG. 16.—Sewage screen, Washington, D.C.

At Roebling, N. J., and Batavia, N. Y., it is understood that mechanically-actuated combing arrangements have been installed, but we are not informed as to the reliability or economy of their performance. Such devices have been designed for Plainfield, but have not been installed, as it is necessary for other parts of the work to have attendants on hand constantly who can readily attend to the cleaning of the screens.

At a number of the larger plants, such as the Metropolitan Sewerage Works in and around Boston, basket screens have been

provided which are lifted from the screen pits to a cleaning room by mechanical appliances such as electric or steam driven hoists. Several such arrangements have been installed but are not considered fully satisfactory. One objection is that many particles are broken by the force of the sewage so that they pass through the screens. Another difficulty is that upon the removal of the screens for cleaning more or less of the removed matters fall back into the screen pit.

Fig. 16, furnished through the courtesy of Mr. Asa Phillips, shows the arrangement of the screens at Washington, D. C., when lifted hydraulically from the pit for cleaning.

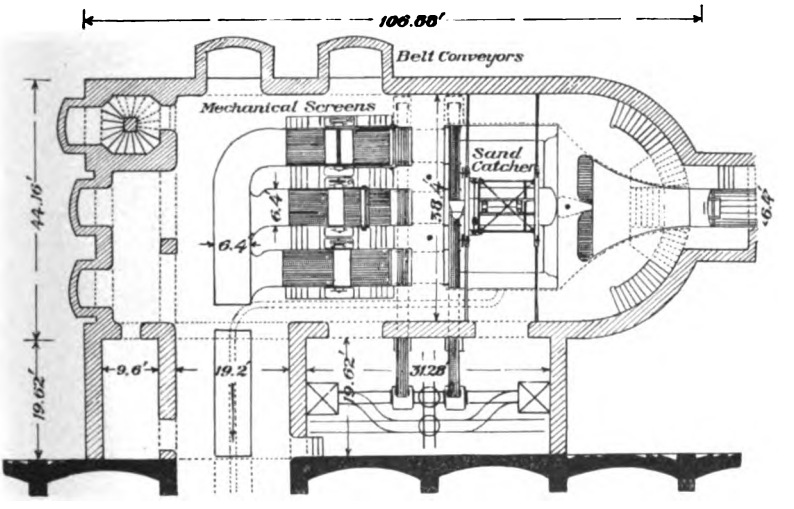


FIG. 17.—Plan of Frankfort screens.

Speaking generally, it may be said that for many small plants use is made successfully of bar screens, with a clear space of about 0.5 inch, and with the cleaning done by hand. Mechanical appliances for cleaning screens in place and even for lifting screens from pits for satisfactory hand cleaning are all matters of detail upon which American data are meager. They are less satisfactory as a guide to designing engineers than are the results available in the numerous books and technical journals as to the European experiences at Hamburg, Frankfort, Cologne, Dresden, Paris, Manchester, etc. We shall not recite those here, but will point out that differences in character of sewage require much

caution in taking too literally the European screening data for adaptation to American conditions.

At Rochester, N. Y., it is understood from Mr. Kuichling that bar screens have been recommended with a clear opening of about 0.37 inch, arranged as revolving blades of the Frankfort type. Originally he states that he recommended a perforated plate screen of this type with slots about 0.08 inch wide and 0.50 inch long. The State Health Commissioner did not approve fine screening alone and demanded sedimentation tanks, whereby it is stated that "the necessity for fine screening is obviously

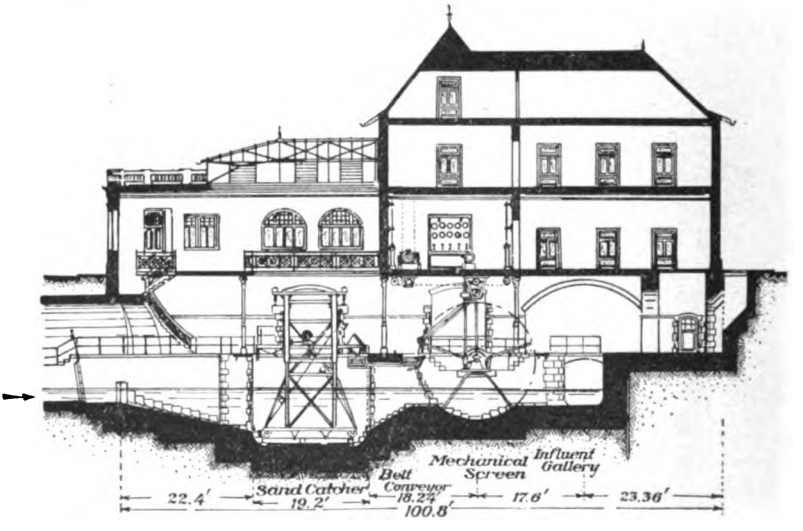


FIG. 18.—Section of Frankfort screens.

removed." In Chapter IX some of the details of this project are outlined. Figs. 17 and 18 show a plan and section of the grit chamber and winged screens designed by Uhlfelder for the Frankfort plant.

THE READING ROTARY SCREEN

Fig. 19, furnished through the courtesy of Mr. Weand, shows a general view of the well-known Reading screen, frequently spoken of as the Weand segregator. It represents the Atlanta screen during its erection at the shop. A patented screen of this type was installed at Reading, with the approval of the author, and it has been in service since 1908. It was installed in the

suction well of the pumping station, and into it is delivered the sewage from separate sewers, mixed with more or less trade wastes. Some of these contain fibrous matter, particularly the discharges from felt hat factories. The Reading device has attracted and has deserved to receive much attention as a step in sewage purification which needs more consideration than it

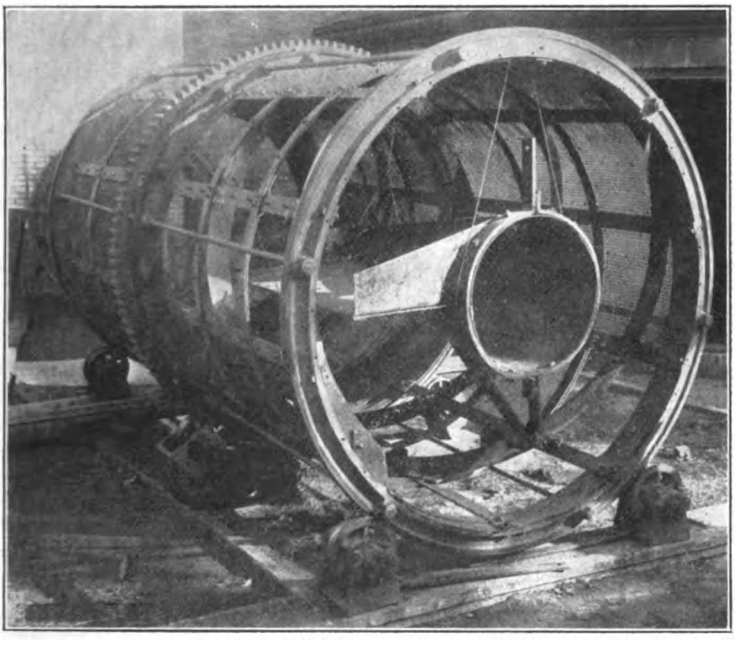


FIG. 19.—Weand segregator.

has received hitherto. Undoubtedly the device as first installed had mechanical shortcomings in that it was not built strongly enough to withstand the use to which it was put. These features have been carefully studied by Mr. O. M. Weand, and he has doubtless made substantial improvements in the later devices.

General Description.—The latest rotary screen of the Reading type is being now installed at the Proctor creek disposal works at Atlanta, Ga. This screen upon the advice of Mr. Hering is located between Imhoff tanks and 1.5 acres of sprinkling filters. Its purpose is to retain floating matters in the settled sewage.

It is being furnished by Mr. Weand for a daily capacity of 3.5 million gallons in accordance with specifications prepared by Messrs. Hering & Fuller, as follows:

Mechanical Screen and House.—Under this item the contractor shall furnish and place a mechanical self-cleaning fine screen, enclosed in a suitable concrete chamber with a brick super-structure. The screen and building shall be complete in all respects, whether or not all parts are herein specifically mentioned.

Screen.—The screen shall be of heavy and durable construction, equal in efficiency to the Weand cylindrical type. The screen cloth shall have not less than 36 meshes per lineal inch, and shall be supported and protected by means of a heavier screen or in some other satisfactory manner. The area of the screen surface shall not be less than 150 square feet.

Screen Drive.—The screen shall be revolved or driven by means of electric motors, properly connected thereto.

Cleaning Screens.—The screen shall be thoroughly and automatically cleaned by means of water or air jets or by some other approved means. Suitable electrically-driven pumps, compressors and necessary piping or other necessary appurtenances for cleaning shall be furnished and installed, and connected with purified sewage or city water.

Discharge of Screens.—The screen shall be arranged so as to discharge the screenings into the chamber shown upon the drawings. Such conveyors, scrapers, etc., as may be necessary in order to discharge the screenings shall be supplied and provided with electric motors and proper connections.

Chamber.—The screen shall be enclosed in a suitable chamber having concrete bottom and walls approximately as shown by the drawings. Stop-plank grooves and stop planks shall be provided so that the sewage may be diverted into a by-pass pipe or may be passed through the screen as desired. Ample working space shall be provided around the screen, and there shall be a concrete floor at a suitable elevation and of sufficient extent to allow the placing of the motors, pumps, switchboards and other devices, and to allow ample room to work about them. Wooden gratings and other coverings of openings in this floor shall be furnished and placed. Beyond the screen there shall be a compartment into which the screenings are to be discharged.

Superstructure.—The screen and screen chamber shall be

enclosed by a brick superstructure with timber and slate roof. The superstructure shall be of the same general character as the laboratory building, and all materials and workmanship shall be at least equal to that structure. A door shall be provided of sufficient size to allow the passage of any part of the apparatus to be placed in the house.

Plans and Specifications.—The contractor shall submit with his bid a full set of plans and specifications, showing the character, construction and method of operation of the apparatus he intends to install.

Compensation.—The lump sum bid for mechanical screen and house shall include all labor, tools, materials and appliances necessary to furnish and construct the screen and its driving, cleaning and other appurtenances complete, together with the concrete substructure and brick superstructure of the building containing it and all stop planks, stop plank grooves, gratings and pipe connections as shown and specified.

Maintenance.—The contractor shall make all the needed repairs on this work as it progresses and during a period of one year after the final acceptance of the work; and he agrees that during the said period of one year the city shall retain out of the moneys payable to him under this agreement the sum of 5 per cent. on the amount of the contract, and that the city may expend the same or so much thereof as may be required in making the aforesaid repairs to the satisfaction of the engineer, if within three days after the delivery or mailing of notice in writing to the contractor or his agents, he or they shall neglect to start the aforesaid needed repairs; provided, however, that in case of an emergency where, in the opinion of the engineer delay would cause serious loss or damage, the city may make repairs without previous notice, and at the expense of the contractor.

Detailed Description.—As stated by Mr. Weand, the machine consists of a rigidly constructed cylindrical frame of steel and iron covered with Monel-metal wire cloth. The mesh is usually 35 to 40 per lineal inch, but varies with the character of sewage to be treated. This cloth is attached to sectional frames 2.5 feet square, which are bolted to the barrel. They are easily and quickly removable and are intended to facilitate quick repair. Attached to these frames is a No. 12 copper wire screen of 1.5-inch mesh which supports the finer screen cloth beneath. Bolted to the interior is a steel worm 4 inches high which serves to carry the

solids forward to the discharge end of the machine, dropping them into a suitable receptacle. The sewage on entering the machine is deposited upon a baffled platform (see Fig. 19) and comes in contact with the screen cloth by falling from the edge of the platform at right angles to the direction of flow from the sewer main. This method enables the liquids to pass through the cloth with great rapidity. The cloth is kept from clogging by a series of jets of water, moving back and forth horizontally along the upper outside of the screen, blowing the clogging matter back into the screen, whence it is carried along with the other solids.

It may be remarked that salt or fresh water, steam or compressed air or even the screened sewage may be utilized for this purpose.

It is stated that the best results are obtained where the flow line of the unscreened sewage as it enters the machine is at or near the central axis. The Atlanta machine was designed to effect a mimimum loss of head, and it will be noted that the bottom of the influent opening is at the same elevation as the bottom of the conduit conveying the sewage to the screen.

These machines usually operate at a speed of 8 to 12 revolutions per minute and require 3- to 5-horse-power motors.

As to repairs one of the difficulties which has been contended with is that at no plant where these machines are now being operated has there been a duplicate installation. That is, one machine is obliged to do all the work. It is manifestly impossible to build any machine that will operate 24 hours daily for 365 days without some wear and interruption for repairs and renewals.

At Baltimore, Md., where screens are being built after plans and specifications prepared under the direction of Mr. C. W. Hendrick, Chief Engineer, there will be two units, and the loss of head is intended to be limited to 1 foot.

Mr. F. Herbert Snow specified that there should be six units for the installation at Atlantic City, N. J., designed to treat a maximum daily flow of 30 million gallons. The size and cost of these screens is not known to us. At Atlanta the screen with its mechanical appurtenances but without the concrete chamber or the superstructure in which to house it cost $3000.

The conditions at New Brunswick, N. J., are such as to require an absolute minimum loss of head, and at times of high water head can only be made available by backing up the sewage in the

main sewer outlet. Under these circumstances much care is needed to prevent objectionable deposits in front of the screen.

The influence of local conditions as to character of liquid to be screened, available head, etc., bears so strongly on the cost that we will not attempt to generalize on this subject.

Operating Results.—At Reading, Pa., where the sewage equals about 100 gallons daily for each person connected with the sewers, the rotary screen removes from 30 to 35 cubic feet of wet matter per million gallons. Mr. E. Sherman Chase gives the following figures for the screenings before and after drying in a centrifuge:

TABLE 56.—COMPOSITION OF SCREENINGS

	From screen	Centrifugalized
Moisture	89.5 per cent.	73.0 per cent.
Mineral matter	2.8 per cent.	7.4 per cent.
Volatile matter	7.7 per cent.	19.6 per cent.
	100.0 per cent.	100.0 per cent.

The screenings are conveyed mechanically to a wooden tank with a sloping bottom and provided with numerous openings through which the free water in part makes its escape. From the tank the wet screenings are put in strong canvas bags holding 1 cubic foot each. Six of these filled bags are put into a 42-inch "hydro-extractor," a centrifuge which revolves at a speed of about 600 revolutions per minute. The free water is reduced by about one-half, so that the centrifugalized screenings, weighing about 35 pounds per cubic foot but of about the same volume as before "drying," are disposed of under the boilers without difficulty. A small quantity of a deodorizer is placed in the centrifuge with each charge. Absence of odors has been characteristic of the Reading Pumping Station, which is located on the river bank in the business part of the city.

One attendant on each 12-hour watch at Reading takes care of the screenings, and this could probably apply to a much larger plant. Mr. Weand estimates that three men could take care of a plant handling 12 million gallons of raw sewage daily of a composition like that at Reading.

At Brockton, Mass., the wet screenings amount to about 50 cubic feet per million gallons of the strong local sewage

RÉSUMÉ

Screens have a far greater field of usefulness than is generally recognized at present in America. There is much room for improvement upon present devices for fine screening. Their utility and standing for the removal of suspended organic matters, in comparison with other devices, will depend upon future data from recent designs and later improvements.

CHAPTER XIII

PLAIN SEDIMENTATION

This process consists in lowering the velocity of flowing sewage so that there are separated from the main body of liquid certain suspended matters of a critical specific gravity or hydraulic subsiding value with respect to the conditions of reduced velocity.

The quality and quantity of suspended matter in sewage affect the results obtained by plain sedimentation. Information upon this question has been set out at some length in Table 15, Chapter I, as to the quantity of suspended matter in different sewages. Briefly, it is to be recalled here that some suspended matters subside quite promptly in basins, others will float upon the surface of the liquid and still others are of such subsiding value that they will pass through the basin and appear in the effluent. The solids which settle to the bottom are called "sludge" which varies much as to its content of water. The floating matters are called "scum." The solids which appear in the effluent are spoken of as "finely-divided particles" and are classed by some as "colloids." The term "colloid" has a complex significance in its distinction from true solutions, semi-solutions and sub-microscopic suspensions. These particles under some circumstances mass together and coalesce; but it is sufficient here to regard them generally as unresponsive to the laws of subsidence.

Fresh sewage with its comparatively large particles of fecal and other suspended matters becomes clarified to a much greater degree by sedimentation than does stale sewage. The reason of this is to be found to a considerable extent in the comminution of the suspended matter in the latter. The particles in fresh sewage which readily subside are converted, when the sewage is allowed to become stale, into a large number of small particles of which many do not subside under the conditions of practice. Entrained gases of decomposition may cause particles to float.

Columbus Classification.—This general phase of the com-

position of sewage was outlined in the Columbus report of 1905 on pages 39–40, as follows:

From a broad practical standpoint colloidal matters may be defined as those suspended particles in sewage which cannot be removed by plain subsidence in a reasonable and economical period of time. Suspended matters of this class are obviously in a very fine state of division, and appear to exist in a state of pseudo solution or micro-suspension.

Such a broad definition of colloidal matter allows various conceptions as to that portion of the suspended matters in sewage which shall be so classed. These so-called colloidal matters are obviously a function of both the velocity of sewage flow and the period of subsidence.

Viewing this question of colloidal matters in a rough, practical way—not in the precise terms of the physical chemist—several interesting observations were made in regard to the local sewage. They relate to the turbidity or suspended matter remaining in the supernatant liquid after bottles of sewage were allowed to rest for many hours, and also to tests of subsidence in several special tanks. On a large scale data were obtained in a 200-foot tank, as recorded in Chapter III of this report.

Speaking generally, it appears that the Columbus sewage ordinarily contains in the neighborhood of 50 parts per million of suspended matter which can be removed by subsidence only in part and with great difficulty in practice. In bottle observations figures one-half of the above have been noted, but, on the other hand, when the sewage was strong, it seemed hardly possible to reduce the suspended matter by subsidence to 50 parts. In fact, from a practical standpoint the opinion gradually developed that on an average about 60 parts per million of suspended matter could be removed in a practical way only by the aid of coagulation or by filtration. That is, only 140 parts, or about 70 per cent., of the suspended matter were logically to be considered in preparatory treatments by subsidence. In this connection it is to be noted that the Columbus sewage more or less resembles some of the clay-bearing river waters of the central west. Further data regarding colloidal matter are contained in the appendices.

HISTORY AND EXTENT OF USE

In its early days sedimentation appears to have been employed as a step in the effort to separate the fertilizing properties of the sewage from the water with which they were diluted. Next came efforts to secure clarification and precipitation with the aid of coagulating chemicals. These steps were first taken with a view to securing the fertilizing properties of sewage on a commercial basis, but later they led to means of clarifying sewage

on its own account after abandonment of hopes of availing of the fertilizing value of sewage under commercially favorable conditions.

Thirty years ago, or just as the germ theory of disease was coming into recognition and bacteriology rose to the dignity of a science, this was by far the prevailing method of sewage treatment.

Next came the so-called biological methods of sewage treatment, and beginning with about 1895 sedimentation played a prominent part in conjunction with the septic process. In those days differentiation between clarification and sludge treatment was illy defined and the substantial benefits of the process due to plain sedimentation were more or less confused with biological claims that were but little understood.

Plain sedimentation during the past decade has come to the front at quite a rapid rate. Not only has it appeared as a separate treatment on its own account in connection with the disposal of sewage by dilution, but it has also established itself as a distinctly helpful adjunct to filtration. In some and perhaps most cases of recently constructed plants sedimentation is a conspicuous portion of the preliminary steps by which sewage is prepared for filtration. The basis of this is that it is found cheaper to clarify sewage and to employ the resulting higher rates of filtration, generally speaking, than it is to apply sewage without treatment directly to filters. Another step which it serves in connection with coarse-grained filters is the detention and removal, from the final effluent, of those comparatively large suspended particles which are unloaded from the filter from time to time and which make the final effluent of unsightly appearance. In the treatment of some trade wastes, particularly in the recovery of by-products, this process may be of aid.

In 1904 the author found that there were about 45 municipal plants in the United States, out of a total of about 91 plants serving towns of 3000 population or over, where sedimentation, including septic tanks, formed a substantial part of the disposal works. Since that date almost all of the more important plants designed or built in America have availed of sedimentation in some form.

In 1911 Mr. Kenneth Allen states, on page 256 of his book on "Sewage Sludge," that there were over 330 municipal sewage treatment works in the United States. Of these about three-

fifths availed of sedimentation in conjunction with the septic treatment, while about one-fifth employed plain sedimentation.

GRIT CHAMBERS

The purpose of grit chambers is to remove from sewage such mineral matters as sand and silt of street washings. Their greatest utility consists in removing those mineral matters, called grit, practically free of putrescible organic matters, so that the disposal of sludge from settling basins without offensive odor is simplified and cheapened. The presence of such grit in settling basins causes difficulty in removal unless slopes to floors and drains are increased above that otherwise required. The usefulness of grit chambers is normally confined to the flow of combined sewers as distinguished from separate sewers receiving household wastes only. If used with the latter, the deposits would be largely organic and there would be substantially no benefit derived either in simplicity or economy as compared with arrangements in which the sludge as a whole is treated. Trade wastes under some circumstances might call for grit chambers in connection with separate sewers.

Aside from their relation to purification plants, grit chambers are of value in protecting some types of pumps from clogging or abnormal wear. There is also another phase of their utility in that they allow coarse matters to be deposited and removed under favorable conditions before the sewage enters some inverted siphons, screening devices or suction wells of pumping stations. Without them deposits in some instances have accumulated under conditions that were bothersome and expensive as to removal. In consequence deposits have been allowed to remain in channels, screen chambers and pump pits, with more or less annoyance.

In connection with the dilution method special study should be given to the need of removing this grit if it may settle in slips or on flats, and to the comparative cost of its removal in different ways.

Adequate data are quite meager, particularly in America, as to the results obtained from different arrangements which have proved satisfactory. The majority of American sewage treatment plants appear to have been built in connection with separate systems of sewers. But where used with combined sewers there is much room for improvement in the employment of grit

chambers, not only in connection with purification arrangements, but also at pumping stations.

Testing stations have not been successful, as a rule, in furnishing satisfactory information on this point.

Columbus Tests.—The Columbus report of Mr. Johnson, on pages 75–88, gives data on attempts to separate grit. It is not believed by the author, however, that they are of much direct practical value to the designer as a general guide for several reasons. In the first place, the shortest detention period (29 minutes) was too long and the highest velocity (11.4 millimeters or 0.46 inch per second) was too low to limit the deposit to mineral matters. This caused a sludge to be obtained with the highest velocity to the extent of about 1.61 cubic yards per million gallons and a great proportion of it was organic matter, subject to putrefaction. Of the dry solids about 46 per cent. was volatile. The chambers were cleaned at intervals of about 6 to 15 days.

Another criticism that may now be made in view of later knowledge and study is that at the Columbus sewage testing station the effect of street wash did not assert itself normally. There were several reasons for this. First, the suction pipe of the pump supplying the testing station was located some 18 inches above the bottom of the 72-inch outfall sewer. This prevented the sewage that entered the testing station from having its pro-rata share of those coarse solids which are found in the lower portion of the sewer and which are spoken of by some as the "bottom drag."

Again, the Columbus and many other sewage testing stations have been operated on the basis of handling an approximately constant volume of sewage flow per day. This means that during heavy rains the normal volume actually treated was not increased in proportion to the higher flow in the sewer. In consequence of this the testing devices, particularly the sedimentation arrangements, treated at times of storms an abnormally small part of the total flow. Owing to the dilution of the sewage after the first flushings were past there was also a frequent diminution in strength. Accordingly, when data from testing stations are compared with those from works in actual practice, it is noted that, at times of heavy storms when street washings have been conspicuous in the increased sewage flow, testing stations have had their load lightened, whereas in practice

the burden is materially increased especially by large quantities of those matters to be taken care of in sedimentation devices. Furthermore, the accelerated velocities of flow through basins in practical operations are sometimes a handicap due to scouring action.

The conclusion was drawn at Columbus that grit chambers were unnecessary, but experience with the main works showed that factors of importance had not been taken into account at the testing station. At the time of making the Columbus tests the grit reaching the intercepting sewer at the testing station may have been abnormally low due to detention within the intercepting sewer or to diversion through numerous overflows into the river from the combined sewers lying over the intercepting sewer. The importance of separating mineral matters alone was recognized at Columbus as stated on page 82 of the report. But efforts to that end were not carried further on account of the observation that the sludge in the inlet half of the chamber showed 36.8 per cent. of volatile matters, while in the outlet half the corresponding figure was 48.5. In view of this fact and of the coarse granular or fibrous character of the sludge, as well as of the very finely divided character of the suspended mineral matter during this period of unusually low rainfall it appears that the Columbus tests were made with a sewage which by no means carried a representative quantity of suspended grit for the flow of combined sewers.

Columbus Experience.—In the large sewage purification plant at Columbus this matter has forced itself to attention in a way that is clearly described by Mr. Julian Griggs in his discussion of Mr. John H. Gregory's paper on the Sewage Works of Columbus in the *Transactions of the American Society of Civil Engineers*, Vol. LXVII, page 326, as follows:

> One defect in the sewerage system and sewage purification works to be regretted is in the sand-catching appliances. It seems to the writer that some mechanical device for cleaning and keeping clean the sand-catcher at the main sewage pumping station should have been installed, for the reason that dependence on hand-cleaning has been found to be unreliable. Soon after the operation of the pumping station was begun the sand-catcher filled to the flow line of the sewer. Since then all detritus arriving in the sewer has been carried forward into the sump chamber where it clogged the sewage-level indicators, and the portion which remained has had to be removed therefrom by hand-cleaning

at more or less frequent intervals. Probably half of the detritus carried to the station in the sewage passed the pumps and was later deposited in the primary septic tanks where, forming layers over the septic sludge, it confined the gases of decomposition and greatly increased the violence of the ebullitions, thus complicating their action. It still remains to be disposed of.

In this connection it may be of interest to state that the interceptors, some twenty in number, on the intercepting sewer are for the most part only pits, one or two feet in depth, in the bottom of each combined sewer, with pipes varying from 6 to 15 inches in diameter leading from the pits to the intercepting sewer beneath the combined sewer at the point of crossing. It is apparent, therefore, that each intercepting pit acts as a sand-catcher for detritus and quickly conveys it to the intercepting sewer. This condition is somewhat mitigated by the fact that in flood flows the smaller interceptors become clogged, and, in that event, a portion of the detritus is carried past the interceptor to the river outlet of the combined sewer.

Three of the interceptors are provided with automatic gates controlled by floats which close the connection to the intercepting sewer at times of storm flow, when, presumably, the greatest proportion of the detritus would be carried in the sewage. These devices have served the purpose intended. It may be that now, however, a new condition has been introduced, which renders them less effective than formerly. The new condition is the daily use of compressed air street flushers, first introduced in 1904; and now, weather permitting, 3 miles of 30-foot streets, or an equivalent area, are washed daily. These flushers simulate the condition of a heavy shower for the area over which they operate, and carry into the sewer catch-basins and the sewer itself a large quantity of detritus. In the area flushed there are 518 street catch-basins, mostly of the standard pit type, 3.5 feet in diameter, and 1.5 feet deep below the siphon outlets; but 9 per cent. of these catch-basins are direct inlets furnished with the so-called Palmer valves. As repairs are needed, these basins are being gradually changed to the standard form with pits.

The intercepting sewer is 6.8 miles long and from 2.5 to 6 feet in diameter, with a grade of 1 per 3000 at its largest diameter, giving a velocity of 2.3 feet per second. It was first put into operation in August, 1894; five years later, in September, 1899, a cleaning of it was begun, which was continued until June, 1900, whereby deposits of from 10 to 15 inches in depth were removed from about 2.4 miles of sewer at a cost of $1.785 per cubic yard, or a total cost of $6,564.81. Nine years later, in July, 1909, deposits upward of 3 feet in depth having accumulated, a second cleaning was begun and is being continued.

While the intercepting sewer is being hand-cleaned it is necessary

to close the interceptors and divert the raw sewage into the river, fouling the same, and thus defeating for a time the purpose for which the sewage purification works have been constructed.

Further data upon the cost and difficulties of cleaning the intercepting sewer at Columbus are given by Mr. Henry Maetzel, who succeeded Mr. Julian Griggs as Chief Engineer of the Board of Public Service, in his report of 1910. A summary of this is found in the *Municipal Journal and Engineer* of Aug. 16, 1911.

Worcester Experience.—Valuable data upon this and other methods for the removal of suspended matter are contained in an excellent paper by Messrs. Eddy and Fales in the *Journal of the Association of Engineering Societies*, Vol. XXXVII, 1906, page 67. Their comments on experiences with grit chambers at Worcester, Mass., are briefly summarized, as follows:

In 1904, two grit chambers were built, each being 10 feet wide, 40 feet long and providing for a depth of about 9 feet of sewage and silt. They were constructed side by side on the line of the 42-inch outfall sewer, and so arranged that the sewage could be turned through one or through both at the same time, as was deemed best.

Experience has proved that with the ordinary flow of sewage, say up to 15,000,000 gallons per 24 hours, too much organic matter is settled out if both basins are in operation. When storm water is mingled with the sewage, at which time the rate of flow is generally above 15,000,000 gallons, it has been found necessary to allow the flow to pass through both chambers to insure the collection of substantially all of the sand and gravel.

Following is a schedule of some of the important statistics gathered from the operation of the grit chambers through a period of something over a year:

TABLE 57.—GRIT CHAMBER STATISTICS

	Customary use of chambers	Two chambers in use at rates below 15 million gallons
Deposit per million gallons of sewage passed through chambers	0.16 cubic yard	0.52 cubic yard
Cost of cleaning chambers and hauling refuse 1,000 feet	$0.81 per cubic yard	$0.95 per cubic yard
Cost of cleaning chambers and hauling refuse 1,000 feet (per million gallons of sewage passed through basin)	$0.13	$0.51
Dry solid matter contained in refuse	50 per cent	30 per cent.
Volatile (loss on ignition) matter contained in refuse	35 per cent.	50 per cent.
Organic nitrogen in dry solid matter	0.75 per cent.	1.00 per cent.
Weight of refuse as removed from chambers	67.2 pounds per cubic foot.	.....

In the consideration of the above figures it should be remembered that there was comparatively little storm water received during the year. This fact would probably not materially affect the amount of refuse per million gallons or the cost of removing the same, but would doubtless affect its weight and the proportion of mineral and organic constituents.

A very offensive odor was always given off from the sludge when it was being removed from the basins and for some time after it had been spread upon the dump. This is a matter deserving serious consideration when the location for grit chambers is to be selected.

No special machinery has been installed for handling this material, it being shoveled out of the basins by hand and hauled away in tip carts.

Later Worcester Data.—In the the report of Mr. Matthew Gault for 1910 it is stated that on 198.66 miles of sewers there are 3251 catch basins. From these there were removed during that year 15,800 cubic yards of refuse material which was carted to the nearest available dump. There were also removed 580 cubic yards of material from the sewers and regulators. On an average 14.57 million gallons daily of sewage were received at the purification works. Practically all of this sewage passed through the above mentioned grit chambers. From the latter there were removed during the year 565 cubic yards of deposit, equalling about 0.11 cubic yard per million gallons. This deposit was removed by shoveling and finally was hauled to a neighboring gravel pit.

Assuming that all of the sewage passes through one of the Worcester grit chambers, the average velocity is about 3 inches, or 75 millimeters, per second when no allowance is made for deposits upon the bottom. Under similar assumptions the period of flow through a chamber is about 2.66 minutes. In practice this velocity is increased and the detention period decreased due to accumulating deposits between cleanings, although when both basins are in service there are times when the velocities are lower and the detention period greater than above stated.

Velocity of Flow.—Bearing in mind that the object of grit chambers is to remove mineral matters to protect pumps, and to facilitate the cleaning of settling basins, and to remove them with a minimum of putrescible matters so as not to complicate its disposal or establish decomposition processes productive of odors of septicization, the question now arises: What is the best velocity and arrangement of grit chambers? This question as to German experiences is well reviewed in Mr. Kimberly's

translation of Dr. Schmeitzner's book on the "Clarification of Sewage," page 2. It is interesting to note that a number of German grit chambers have been re-designed and modified when extensions have been made. The velocities now recommended approximate 1 foot per second. With varying volumes of sewage this velocity appears to be maintained in the newer German works by having a number of compartments of which one or more are in use depending on the volume of sewage flow.

In the Emscher district Mr. Saville states in his paper before the Boston Society of Civil Engineers in December, 1910, that the grit chambers are built in duplicate with their floors 15 to 18 inches below the invert of the sewer and designed so that the velocity of flow in dry weather shall be more than 1 foot per second. Under these conditions he states that nothing but clean sand is deposited. On the bottoms of the grit chambers are tile drains covered by cinders. In closing off a grit chamber the water seems to pass quite rapidly through the sand and cinders, thus allowing the inodorous sand to be quickly removed and to become available for surfacing the sludge-drying beds. The chambers are cleaned out every two or three days, or whenever the deposited sand rises to the level of the inlet.

Detention Period.—Mr. Kuichling in his paper in 1908 before the New Jersey Sanitary Association speaks of the unsettled practice as to grit chambers. He emphasizes the mineral character of the material so to be removed and points out that for the most part it will subside within one minute. In some instances grit chambers have been built to provide a subsidence period of from 5 to 10 minutes. He states that the grit chambers at the head of the large inverted sewer siphons under the Seine at Paris are from 100 to 600 feet long and the normal velocity of flow is from 6 to 8 inches per second. In some other cities he finds that the lengths of the grit chambers are from 30 to 60 feet with the velocity of flow reduced to 2 or 3 inches per second.

Volume of Grit.—As to the volume of grit removed in such grit chambers, Mr. Kuichling speaks of various experiences. At Manchester, England, the deposit with screenings amounts in dry weather to about 8 cubic feet per million United States gallons of sewage. During rainstorms this volume is increased about 50 per cent. About one-third of the material so deposited is combustible. At Boston, Mass., the detritus removed from the settling chamber of the Dorchester sewage pumping

station during 1903 averaged about 8.33 cubic feet per million gallons. This is about the same figure as given by Messrs. Rafter and Baker, page 183 of their book, for the deposits removed from the "deposit sewers" of the Boston Main Drainage Works in 1887. These sewers, about a quarter of a mile long, are in duplicate, 8 feet wide and 16 feet deep, located just above the tunnel sections leading to the Moon island outfall. This is also the approximate figure in 1910 when the sewage flow averaged 82.4 million gallons per 24 hours. This corresponds to a velocity of about 2 feet per second when the depth of flow equals about 8 feet. At the experiment station of the Massachusetts Institute of Technology in Boston, Profs. Winslow and Phelps state that about 0.65 cubic yard of detritus per million gallons of sewage was removed when the detention period was 45 seconds. About 6.65 per cent. of the grit was volatile.

At Paris the sewage flow through various grit chambers in the main sewers as estimated by Mr. Kuichling produces about 23.5 cubic feet of grit per million United States gallons of the strong local sewage. This computation is said not to take into account storm flows and probably would be reduced if very accurate data were available for computation. Two stations at Berlin are stated by Mr. Kuichling to have shown records in 1900 according to which there were removed from grit chambers and sewers about 4.8 cubic feet of grit per million United States gallons. At Wiesbaden he states the rate in 1902 to have been 10.1 cubic feet.

Speaking generally, the volume of normal grit usually varies from about 6 to 12 cubic feet per million gallons. It depends upon the kind of pavement, the nature of the soil of unpaved streets, the arrangement and frequency of cleaning of catch basins, the proportion of storm overflows which are bypassed around the grit chamber, and the arrangement and frequency of cleaning of the grit chambers.

Style of Structures.—In considering the arrangement of grit chambers, Mr. Kimberly in his translation of Dr. Schmeitzner's work speaks on page 54 of several different styles of designs of which from general experience preference is given to that shown in Fig. 20.

In this connection it must be clearly borne in mind, as emphasized by the early Columbus and Worcester experiences, that velocities of flow must be kept relatively high. They must be

secured either by a number of compartments side by side, or by the use of velocities which at times of wet weather will remove little other than very coarse sand. If single compartments remove more than coarse sand during storm flows, they will remove too much putrescible matter at times of dry-weather flow. Multiple compartments are preferable, with units following the general arrangements of Fig. 20.

The aggregate length of the compartments should be such as to provide for retaining the grit of heavy storm flows and with some margin for storage at the beginning of a storm. In summer the chambers should be cleaned once a week or oftener.

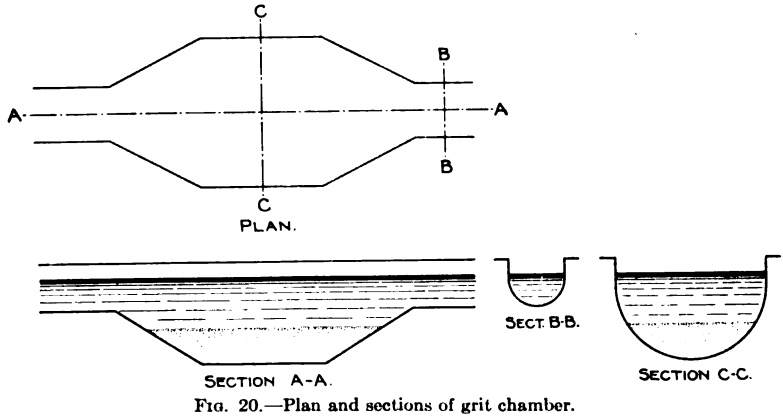


FIG. 20.—Plan and sections of grit chamber.

Percentage of Water.—As to the percentage of water in the mineral sludge of grit chambers, that may be ignored, practically speaking. Of course, the voids of the material may be filled with water wholly or to a considerable extent, but this has no special significance in regard to the disposal of the sludge, provided care is taken, as repeatedly pointed out above, to keep it of a mineral and not organic character. With a proper design the grit removed from the chambers may be satisfactorily used for filling, without trouble from offensive odors.

SEWAGE SKIMMING TANK, WASHINGTON, D. C.

Fig. 21, furnished by Mr. Asa Phillips, shows a section of the sewage skimming tank at Washington which has attracted much favorable comment. It is located at the end of the discharge

conduit coming from the pumps and at the head of the siphons under the Anacostia river. The sewage flow from the main discharge conduit rises above the siphon outlet. This causes certain materials in the sewage to rise to the surface and there oscillate due to the eddying effect within the tank. This action rolls up the grease which attaches itself to match stems, corks and some other solid matters which pass through the screens. This material amounts to about 100 pounds per 24 hours. It

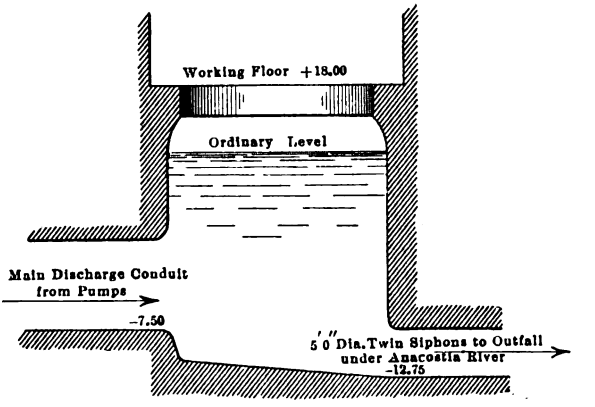


FIG. 21.—Sewage skimming tank, Washington, D. C.

is removed by skimming from the circumferential platform above the level of the sewage and is burned as a waste. This feature could be advantageously employed at some other places where large volumes of partially treated sewage are disposed of by dilution.

GREASE REMOVAL. KREMER APPARATUS

The removal of grease, amounting in ordinary sewage to about 20 grams per capita daily, is of some advantage in guarding against sleek on diluting water and against certain clogging features when sewage is applied to very fine-grained filters.

Grease is better removed by flotation than by sedimentation. Except as to use with trade wastes, experience is lacking as to the systematic removal of fatty substances from American sewages. In some degree it is retained by scumboards at and just below the surface of the liquid in settling basins.

The Kremer apparatus shown as Fig. 22 is a device which has been carefully studied in Germany for the separation of fatty scum. The grease layer is stated to contain about 72 per cent. of water and there is about 45 per cent. of grease in the dried material. After further drying it is used by soap makers. The sludge may be treated with tetra-chloride of carbon to extract fats. Mr. Allen's translation of Elsner's article on Sludge Treatment, page 109, indicates that the practicability of sludge treatment for grease begins with a population of about 45,000 connected with the contributing sewers.

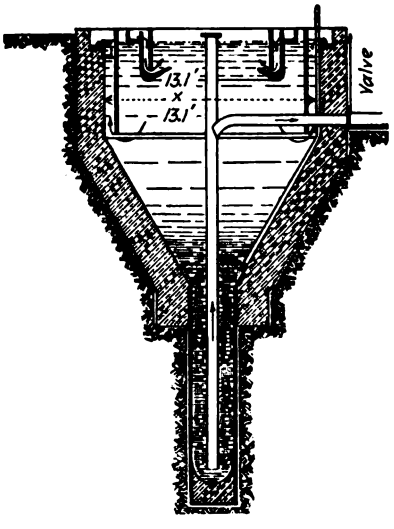


FIG. 22.—Kremer apparatus.

THEORY OF SEDIMENTATION

Sedimentation is a function of a complicated series of factors. In America the subject has been studied practically and theoretically more with regard to water than sewage clarification. Probably the best discussion of the subject has been written by Mr. Allen Hazen in a paper in the *Transactions of the American Society of Civil Engineers*, Vol. LIII, page 45. This paper is theoretical in its nature and focuses particularly on a number of the more important factors considered arbitrarily as free of certain other factors, all of which in practice admittedly obscure

the analysis of the relation between cause and effect. Nevertheless it throws more light on our understanding of a complex subject than any other writings with which the author is familiar. The paper as a whole is well worthy of most careful study. It accentuates many thoughts that the author considers as a clue to recent improvements in sedimentation basin designs and is so suggestive of a number of lines upon which ideas need further elucidation, that it is quoted from at considerable length, as follows:

Hazen's Discussion.—Since Seddon published his paper on "Cleaning Water by Settlement," there has been but little published discussion on the theory of this subject, but the practice of building and operating sedimentation basins has advanced materially. For example, it has been found in St. Louis that continuous operation, that it to say, a continuous flow of water into, through and out of the basin, gives quite as good results as the intermittent operation which was studied by Seddon, and the new arrangement allows the effluent to be delivered at a higher level, the economical advantage of which is evident. The use of baffles has also been learned, and it has been shown clearly that a well-baffled basin will do as much work as a much larger basin without baffles. A discussion of the subject from a theoretical standpoint, in view of these developments, may lead to a better understanding of it, to the collection of better data, and to improvements in design.

The processes which take place in sedimentation are extremely complex; to discuss them at once in their entirety seems hopeless. First, conditions much simpler than those which actually exist must be assumed, and from these simple assumptions the more complex conditions can be approached.

General Assumptions.—Let it be assumed, first, that whenever a particle of suspended matter hits the bottom it remains where it strikes and is never carried forward on the bottom or picked up again; second, that all the sediment in the water is of the same hydraulic value; that is to say, that every particle settles through water at the same rate as every other particle.

Let t = the time required for a particle of sediment to fall from the surface to the bottom of the water in the basin, the water meanwhile being absolutely still;

a = the time of sedimentation in case the action is intermittent; and, in case of continuous operation, let a be the quotient obtained by dividing the capacity of the basin by the quantity of water entering or leaving it during each unit of time;

n = the number of basins, in case several basins are used successively;

x = the proportion of sediment remaining at the end of the process, the amount at the beginning being taken as unity.

Proposition 1.—*Assume a basin full of water containing sediment, the water being absolutely at rest and so remaining.*

Under these conditions, each particle of sediment will settle toward the bottom at its determined velocity. At the end of a certain period all the particles will have been removed from a top layer of water, which layer will be as thick as the distance that a particle will fall in the elapsed interval, while an amount of sediment equal to that originally contained in the cleared layer at the top will have been deposited upon the

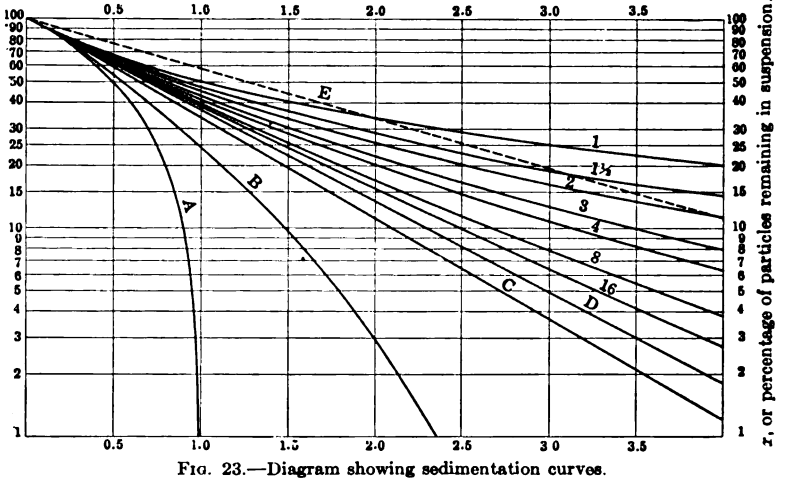


FIG. 23.—Diagram showing sedimentation curves.

$\frac{a}{t}$, or time of settling, in terms of time required for one particle to settle from top to bottom.

bottom. The time required for the removal of all the sediment will be the time required for a particle to settle from top to bottom, or t; and the proportion removed in a shorter period, a, will be $\frac{a}{t}$; and the proportion remaining will be one, less this amount. We then have

$$x = 1 - \frac{a}{t} \qquad (1)$$

The values of x for various values of $\frac{a}{t}$ are plotted in Fig. 23 as Line A:

In an actual settling basin the water is mixed more or less from top to bottom in the process, with the result that the sediment does not go down in the manner indicated by the assumption. The most important causes of motion are:

1. The kinetic energy of the water as it enters, which, according to Seddon, is still capable of producing vortex motion after long periods, but which can be much reduced by controlling the water at the entrance so that it has only a very low velocity.

2. The action of wind (acting in open, but not in covered, basins).

3. Changes in temperature, which, even though slight, change the specific gravity of the water and produce currents in it.

A development of this proposition, and of the motions of the water, and the resultant mixings, is given in much detail in Seddon's paper.

Mr. Hazen next proceeds to discuss 14 other propositions dealing with factors of mixing, method of operation, degree of baffling, depth, bottom velocities, bottom areas, particles of various hydraulic subsiding values, and similarities between sedimentation and filtration. We refer the reader to the original paper for these interesting details.

Limiting Effect of Viscosity.—One practical feature of sedimentation is developed, and that is that viscosity of water controls the subsidence of very small particles. It suggests a reason for the well-known observation that no practical benefit follows a reduction in velocity below certain limits. We continue our quotation from this paper:

ON THE VELOCITY AT WHICH PARTICLES OF SEDIMENT SETTLE THROUGH STILL WATER

The larger particles settle rapidly, the smaller ones very slowly. With very small particles the viscosity of water controls, and the velocity of settlement, or the hydraulic value, varies as the square of the diameter. With large particles friction controls, and the velocity or hydraulic value varies as the square root of the diameter. There is a transition space between. This space covers particles from 0.1 to 1.00 millimeter in diameter, or ordinary sand, and also extends somewhat beyond these limits.

TABLE 58.—VELOCITIES AT WHICH PARTICLES OF SEDIMENT FALL IN STILL WATER

Diameter of particles, in millimeters	Hydraulic value in millimeters per second. 10° C. = 50° F.	Remarks
1.00	100	Experiments by the writer.
0.80	83	Experiments by the writer.
0.60	63	Experiments by the writer.
0.50	53	Experiments by the writer.
0.40	42	Experiments by the writer.
0.30	32	Experiments by the writer.
0.20	21	Experiments by the writer.
0.15	15	Experiments by the writer.
0.10	8	Experiments by the writer.
0.08	6	Interpolated from connecting curve.
0.06	3.8	Interpolated from connecting curve.
0.05	2.9	Interpolated from connecting curve.
0.04	2.1	Interpolated from connecting curve.
0.03	1.3	Interpolated from connecting curve.
0.02	0.62	Wiley's formula.
0.015	0.35	Wiley's formula.
0.010	0.154	Wiley's formula.
0.008	0.098	Wiley's formula.
0.006	0.055	Wiley's formula.
0.005	0.0385	Wiley's formula.
0.004	0.0247	Wiley's formula.
0.003	0.0138	Wiley's formula.
0.002	0.0062	Wiley's formula.
0.0015	0.0035	Wiley's formula.
0.001	0.00154	Wiley's formula.
0.0001	0.0000154	Wiley's formula.

Note.—These values are not given as being precise, but they are believed to be sufficiently accurate for the purpose of this discussion.

The hydraulic values of particles within these limits have been determined by noting the time required for settlement for a determined distance through water in a glass vessel. Particles of different sizes were obtained by the methods used in the mechanical analysis of sand. The specific gravity of the particles is about 2.65. The grains are irregular, and the diameters are taken as the diameters of spheres of equal volume.

For particles less than 0.025 millimeter in diameter, the formula given by Wiley is used, namely, $d = 0.0255v^2$, the diameter being in millimeters and the velocity in millimeters per second. The hydraulic values of particles from 0.025 to 0.1 millimeter in diameter have been obtained by drawing a curve between the lines representing the higher and lower values. Some of these values are given in Table 58.

ON THE EFFECT OF TEMPERATURE

The figures in Table 58 are for a temperature of 10° Centigrade or 50° Fahrenheit, which is about the annual average temperature of the water in the northern part of the United States. The finer particles settle more rapidly as the water becomes warmer, but with the coarser ones temperature makes less difference. For the finest particles, the rate of settling at different temperatures varies as $\frac{t+10}{60}$, t being the temperature on the Fahrenheit scale. The relative hydraulic values of the same particles at different temperatures are as follows:

Temperature, Fahrenheit	Relative hydraulic value
32	70
38	80
44	90
50	100
56	110
62	120
68	130
74	140

At a summer temperature of 74°, a particle of sediment will settle twice as fast as at the freezing-point. In other words, a given sedimentation basin will do twice as much work in summer as in winter. That is to say, twice as much water can be treated with the same results. Experience indicates the truth of this deduction, and it is also true of filters.

ON THE EFFECT OF FLOCCULATION AND COAGULATION

By flocculation is understood the gathering together of the particles of sediment into aggregates. This takes place more or less with clayey sediment. It is probably not a very important matter in sedimentation basins, because the opportunities for it in rivers before the water enters the sedimentation basins have been so favorable that it has gone as far as it will readily go before the water enters the basin.

Coagulation is artificial flocculation, and is caused by the addition of a chemical to the water. The effect of flocculation or coagulation is to increase the size of the particles, for the aggregates formed in this way have subsiding values which may be very much larger than the subsiding values of their individual particles. Salt water induces flocculation, and the increased rate of sedimentation when fresh water mixes with salt water is to be explained in this way; for it cannot be

supposed that an individual particle would settle faster in salt water than in fresh.

HAZEN'S RÉSUMÉ

The fundamental proposition, in clearing water by sedimentation, seems to be that every particle of sediment moves downward through the water at a velocity depending upon its size and weight and upon the viscosity of the water. Particles of sediment are generally so far apart that they do not influence each other; and, while there is no doubt that they do sometimes collect in groups and thus change the conditions, it seems to be generally true that each particle will settle as if no other particles were present.

If the water in a basin were absolutely quiet there would be a regular sequence of clearing beginning at the top. The coarsest particles would go down fastest, but at any given point there would be a gradual clearing, and this clearing would take place most rapidly at the top, and, after longer intervals, at lower points in the basin.

Seddon started out with this theory, but found it to be not in accordance with the facts. His observation showed that while the amount of sediment in the water in the top was a little less than in the water in the bottom, the distribution was nearly equal throughout the mass, a condition of affairs inconsistent with the theory. He accounted for this distribution of sediment by the constant mixing of the water from top to bottom, and to the sustaining power of vortex motions in the water. These motions he thought arose from the internal motion of the water at the time of entrance, and from wind, and from temperature changes.

The writer has taken Seddon's development of the case as his starting-point, and has carried the discussion further. He believes that while the internal motions keep the water mixed, and with nearly the same density of sediment from top to bottom, the tendency of the particles of sediment to settle is nevertheless an unbalanced force always acting to take the particles to the bottom, and the number of particles that hit the bottom in a given time is proportional, first to the velocity at which the individual particles settle, and second to the density of sediment in the water immediately above the bottom.

With these fundamental relations in mind, it is easy to compute and to express by simple formulas the proportions of particles of sediment of a given hydraulic value which will hit the bottom under given conditions and which, therefore, presumably, will be removed.

The fundamental propositions may be very concisely expressed. They are: First, that the results obtained are dependent upon the area of the bottom surface exposed to receive sediment, and that they are

entirely independent of the depth of basin; and second, that the best results are obtained when the basins are arranged so that the incoming water containing the maximum quantity of sediment is kept from mixing with water which is partially clarified. In other words, the best results are obtained where any given lot of water goes through the basin with the least mixing with the water which entered before it, and with the water which enters after it. This is practically accomplished by dividing the basins into consecutive apartments by baffles or otherwise.

Thus far the discussion is easy and apparently certain. The next step is a more difficult one. It relates to bottom velocities, and has to do with the question whether these velocities are such as to allow the particles to remain on the bottom when they get there, or whether they will be taken up again and be kept in motion with the body of the water. This is a point upon which further experimental data are needed. The problem of securing such data seems to be difficult. The observations must be made at the bottom of a layer of liquid of considerable thickness, where the conditions of observation are not favorable. The observations further, must be made on very low velocities and on particles so small as to be practically microscopic.

Whatever view may be taken of the second part of the problem, or whatever researches upon it may show, the arrangements of basins most favorable to taking particles to the bottom should stand.

The computations made in this paper show the reasons for several forms of construction already successfully used, and suggest further possible improvements in design.

REMOVAL OF IMPURITIES BY SEDIMENTATION

Data are disappointing and meager to show the efficiency of sedimentation. This is explained in part by the fact that many of the recent investigations of sedimentation have been closely allied and somewhat confused with the septic treatment. In part it is also due to difficulty in getting from a limited number of observations reliable data as to representative samples of influent and effluent.

Total Suspended Solids.—In round numbers it may be said that by means of sedimentation it is feasible to deposit about 50 to 75 per cent. of the total suspended matters in American sewages. About 65 per cent. is a fair average for economical limits. Probably the best available data on this subject were those obtained at the Columbus sewage testing station. As far as sampling and analyses are concerned, they leave but little to

be desired. As a guide to what may be obtained in practice, however, they have one shortcoming in that the velocities of flow were substantially constant, thereby eliminating the disturbing influence of increasing velocities and corresponding scouring action upon the sediment or sludge on and near the bottom of the tank.

Settling Solids.—Dr. Imhoff has pointed out that the practical conceptions as to the efficiency of sedimentation are considerably disguised by the custom in America of computing the results in percentages of removal of total suspended matter. His procedure has a number of features to commend it. It is that of stating the percentage removal of suspended matters which are capable of deposition in practice. He determines the amount of settling solids by allowing a bottle of sewage to remain quiet for a period of two hours. He claims properly that the matters still in suspension after this period are so fine that they do not relate to the process of sedimentation. This feature was taken up at the Philadelphia sewage testing station during the closing months of its operation; also at the Chicago testing station. It will be helpful to proceed hereafter along that line, at least to the extent of getting comparative data with those by earlier methods. According to the statements of Mr. Pearse, it is not feasible to use the German conical glasses for measuring satisfactorily the volume of the deposited solids in very dilute American sewages.

The data in Table 59 are taken from the report of Mr. Johnson on the Columbus tests, pages 151–53. They are averages of many hundreds of observations, and errors of sampling are believed to have been eliminated. The capacity of the various tanks studied are given in terms of the period of flow necessary to fill the respective tanks. It corresponds with what the Germans call the "flowing through" period. This period of detention or retention capacity is the most convenient way of comparing different sedimentation basins, although it may obscure quite important details resulting from the particular arrangement of the tank in question.

TABLE 59.—PERCENTAGE REMOVAL OF CONSTITUENTS OF SEWAGE IN SEDIMENTATION BASINS OF DIFFERENT SIZES AT THE COLUMBUS TESTING STATION

	Capacity of tanks in hours' flow			
	0.3	1.5	6.0	8.0
Total suspended matter	22	34	63	66
Volatile suspended matter	19	29	54	58
Total settling suspended matters	33	51	96	100
Nitrogenous organic matters	10	19	30	31
Carbonaceous organic matters	6	15	26	31
Fats	18	.....	.....	50
Cubic yards of sludge per million gallons (87 per cent. water).	1.76	2.55	5.75	.....

In comparing these Columbus data with the original it will be noted that the author has added the third line to show for the different tanks the relative percentages of removal of total settling suspended matter. This is figured on the basis that 100 per cent. removal of the settling solids was found in practice to occur at Columbus in an 8-hour tank. It is given for what it is worth with a view to accentuating the amount of work done by basins which at the time of the Columbus tests would have been considered very small indeed.

During the regular period of tests at Columbus observations on sedimentation were made in tanks which were 40 feet long, 8 feet wide, 8 feet deep at one end and 9 feet deep at the other. Ordinarily these tanks were operated with the sewage level about 12 inches from the top. This gave a gross capacity of 17,600 gallons without any allowance for sludge accumulation. The ordinary velocities of flow were about 0.42 and 0.56 millimeter or 0.017 and 0.022 inch per second, corresponding to flowing through periods of 8 and 6 hours, respectively.

Special Test in 200-foot Tank.—At the close of the regular tests at Columbus the several experimental tanks were remodeled so that the sewage could flow through special openings in the division walls at the opposite ends of the five tanks which were built side by side. The effective cross-section of the tanks remained about 56 square feet, with an effective depth of 7 feet. This was also the dimension of the openings cut through the successive alternate ends of the division walls. It gave a total

length of travel of 200 feet and the sewage flow was controlled at a velocity of about 4 millimeters or 0.16 inch per second. Screened sewage was brought in at the end of the first tank through a six-inch pipe situated 1.25 feet below the water level and 2.5 feet from the side of the tank. In front of the inlet discharge was a baffle or box 2 feet by 2 feet. The outlet was provided with a notched weir and the flow was controlled through the aid of hook gage readings at this point at half-hourly intervals.

With much care samples were collected during a period of 72 hours of continuous observation. They were taken at half-hourly intervals from three points 1, 3.5 and 6 feet respectively beneath the surface. The results of these observations are shown in Table 60. They give the detail data for the samples collected at the inlet and as it passed through each 40-foot length of flow, as well as samples at the different depths. Those marked "A" were collected one foot beneath the surface and samples "B" and "C" were collected 3.5 and 6 feet respectively beneath the surface. The average samples represent a mixture of equal portions collected from the three depths. Table 61 shows these data for the three days in question with their varying quality of raw sewage and with the results averaged by 8-hour periods to emphasize the differences in initial strength of sewage. Under "A," "B," and "C" the results are averaged for the periods 8 a. m.–4 p. m., 4–12 p. m. and 12 p. m.–8 a. m., respectively.

Due allowance was made for the period of travel from the inlet to the sampling station in collecting and recording the samples here tabulated.

Several features are shown clearly by these tests as follows:

1. There was not much difference in the amount of suspended matter at different depths within the range observed.

2. That after the sewage had flowed a distance of 120 feet, corresponding to a period of 2.5 hours, there was comparatively small improvement in the clarification of the sewage due to its subsequent flow through the remainder of the tank. Indeed most of the work was accomplished during the flow in the first length of 40 feet, although there was a considerable clarification in the second compartment corresponding to a total length of flow of 80 feet and equal to 1.7 hours for the total period of flow.

3. Quite marked variations were noted in the strength of the

sewage on different days as well as different hours, and the percentage removal was distinctly greater for the strong than it was for the weak sewage. Furthermore, the residual suspended matter or non-settling solids did not vary much during the different days when there were rather marked differences in the quality of unsettled sewage. Evidently more or less mixing took place. Further comments made in Mr. Johnson's report, pages 104–9, are of interest on the relative removals of volatile and suspended matter.

How far these data may serve as a basis for the design for practical works, however, is a different matter. Caution should be used on account of the absence of the irregularities in the volume of flow, with the attendant scouring action on the bottom. Probably some allowance should be made for the size of the tanks which would tend to promote uniform displacement to a greater extent than obtains in large basins in practice. Initial velocities and vortexual motions are also checked more quickly in small than in large basins, due to the friction of the liquid against the walls of the tank. In small basins the mixing is likely to be less on account of convection currents due to temperature changes. With open basins the wind does more mixing in small than in large ones.

TABLE 60.—REMOVAL OF SUSPENDED MATTER BY SEDIMENTATION. RESULTS TO SHOW REMOVAL AT DIFFERENT PERIOD AND DEPTHS

Length of travel, feet	Period of flow hours	Temperature degrees Fahrenheit		Total suspended matter: Parts per million				Total suspended matter: Per cent. removed: For each 40 feet of travel				Total suspended matter: Per cent. removed: Total			
		Influent	Effluent	A	B	C	Av.	A	B	C	Av	A	B	C	Av.
July 11, 8 a. m. to July 12, 8 a. m.															
0	0.0	71	.....	149	149	149	149	.....	.....	.....	.....	.....	.....	.....	.....
40	0.8	.....	.....	110	109	107	109	26	27	28	27	26	27	28	27
80	1.7	.....	.....	84	91	86	87	18	12	14	15	44	39	42	42
120	2.5	.....	.....	72	82	72	77	8	6	10	6	52	45	52	48
160	3.3	.....	.....	78	65	75	73	0	11	0	3	48	56	50	51
200	4.2	.....	.....	67	73	70	70	3	0	0	2	55	51	50	53
Weir		.....	72	68	...	...	68	.....	.....	.....	.....	54	.....	.....	.....

July 12, 8 a. m. to July 13, 8 a. m.

0	0.0	70	.....	196	196	196	196	...	...	...	...	...	...	...	...
40	0.8	.....	.....	108	125	110	114	45	36	44	42	45	36	44	42
80	1.7	.....	.....	90	100	100	97	9	13	5	9	54	49	49	51
120	2.5	.....	.....	87	87	77	84	2	7	12	6	56	56	61	57
160	3.3	.....	.....	86	85	75	82	0	1	1	1	56	57	62	58
200	4.2	.....	.....	85	76	63	75	1	4	6	4	57	61	68	62
Weir		.....	71	72	...	...	72	...	...	...	...	63	...	...	...

July 13, 8 a. m. to July 14, 8 a. m.

0	0.0	70	.....	318	318	318	318	...	...	...	...	...	...	...	...
40	0.8	.....	.....	89	114	108	104	72	63	66	67	72	63	66	67
80	1.7	.....	.....	65	78	73	72	8	12	11	10	80	75	77	77
120	2.5	.....	.....	70	68	59	66	0	4	4	2	78	79	81	79
160	3.3	.....	.....	66	65	58	63	0	1	1	1	79	80	82	80
200	4.2	.....	.....	61	60	54	58	1	1	1	2	81	81	83	82
Weir		.....	71	55	...	...	55	...	...	...	...	83	...	...	...

Notes.—"A" Samples collected at a point 1 foot beneath surface. "B" Samples collected at a point 3.5 feet beneath surface. "C" Samples collected at a point 6 feet beneath surface, 1 foot from bottom. "Av" equals average of samples at the three depths.

TABLE 61.—RESULTS SHOWING REMOVALS BY SEDIMENTATION OF TOTAL SUSPENDED MATTER IN STRONG, MEDIUM AND WEAK SEWAGES

Length of travel in feet	Period of flow in hours	Temperature degrees Fahrenheit		Total suspended. matter											
				Parts per million				Per cent. removed							
								For each 40 feet of travel				Total			
		Influent	Effluent	A	B	C	Av.	A	B	C	Av.	A	B	C	Av.

July 11, 8 a. m. to July 12, 8 a. m.

0	0.0	71	.....	215	133	98	149	...	...	...	...	...	...	...	...
40	0.8	.....	.....	144	104	78	109	33	22	20	27	33	22	20	27
80	1.7	.....	.....	114	87	60	87	14	12	19	15	47	34	39	42
120	2.5	.....	.....	96	79	57	77	8	6	3	6	55	40	42	48
160	3.3	.....	.....	89	65	64	73	4	11	0	3	59	51	35	51
200	4.2	.....	.....	84	63	64	70	2	1	0	2	61	52	35	53
Weir		.....	72	85	54	64	61	...	...	...	...	60	52	34	59

July 12, 8 a. m. to July 13, 8 a. m.

0	0.0	70	.....	348	184	57	196	...	...	...	....	....	....	....	....
40	0.8	.....	.....	179	120	44	114	49	35	23	42	49	35	23	42
80	1.7	.....	.....	143	97	43	97	10	12	2	9	59	47	25	51
120	2.5	.....	.....	123	88	40	84	6	5	5	6	65	52	30	57
160	3.3	.....	.....	113	81	48	82	2	4	0	1	67	56	16	58
200	4.2	.....	.....	106	73	46	75	3	4	0	4	70	60	19	62
Weir		.....	71	97	71	49	72	...	...	...	....	72	61	14	63

July 13, 8 a. m. to July 14, 8 a. m.

0	0.0	70	.....	318	129	53	167	...	...	...	....	....	....	....	....
40	0.8	.....	.....	166	94	51	104	42	27	4	38	42	27	4	38
80	1.7	.....	.....	98	77	41	72	27	13	19	19	69	40	23	57
120	2.5	.....	.....	84	66	47	66	5	9	0	3	74	49	8	60
160	3.3	.....	.....	85	61	43	63	0	4	0	2	73	53	19	62
200	4.2	.....	.....	78	54	44	59	2	5	0	3	75	58	17	65
Weir		.....	71	68	50	46	55	...	...	...	....	79	61	13	67

Reading Experiences.—Mr. Chase has communicated to the author the results of examinations of the turbidity of screened sewage in flowing through the main preliminary settling tank at Reading. This tank is about 250 feet long, 50 feet wide, and 16 feet deep. Two sets of observations were made, the first at a velocity of 3.7 millimeters or 0.15 inch per second; and the second set at a velocity of 4.5 millimeters or 0.18 inch per second. Turbidity samples were collected about 65 feet from the inlet end and in Table 62 are marked "inlet" samples. Those marked "outlet" samples were collected about 30 feet from the outlet end.

The samples at different depths were collected by fastening a long piece of rubber tubing to a long iron rod. The distance below the surface of the end of the tube was then adjusted and the samples collected by siphoning the sewage over the side of the tank. Samples were collected about 2 feet from the side walls. This method of collecting samples allowed portions to be removed just above the sludge surface and, as Mr. Chase states, affords a good method of recording the amount of sludge in the local tank before draining for cleaning. When the tube reached the sludge it became plugged and no sample could be taken.

The samples were compared as to turbidity with standard preparations of diatomaceous earth, following the custom at water purification plants. This is feasible at the Reading plant where the sewage is first passed through a fine screen and where at no step in the complete process is the sewage devoid of dissolved oxygen.

In noting the data in Table 62 it is to be stated that a 2-hour interval elapsed between the collection of the two sets of samples. This does not mean, however, that the results for the inlet and outlet samples refer to the same body of sewage, or that there was a well defined relation between turbidity and velocity of flow within the limits noted. The principal feature to be observed is that there was no well defined difference in turbidity at different depths. In particular was the sewage stratum immediately above the surface of the sludge of about the same turbidity as noted in samples collected nearer the water surface. The distance from the surface of the sewage to the sludge surface varied in the two sets of observations. This is due to the increased head on the outlet weir at the higher velocity of flow on account of the greater friction to be overcome as the increased volume of settled sewage flowed through a pressure pipe for about half a mile to the sprinkling filters on Fritz's island. Mr. Chase states that the surface sample near the outlet in the second set of observations was due to an upheavel of sludge which took place a few moments before taking this sample.

TABLE 62.—TURBIDITIES IN PARTS PER MILLION AT DIFFERENT DEPTHS IN THE READING SETTLING TANK

Depth	First set		Second set	
	Inlet	Outlet	Inlet	Outlet
Surface	205	110	220	175
5 feet	185	115	240	120
10 feet	200	120	225	115
13 feet 5 inches	180	.....	.....	.....
13 feet 7 inches	190	.....	.....	.....
13 feet 8 inches	Sludge	.....	.....	.....
13 feet 11 inches	.....	.....	215	.....
14 feet	.....	.....	215	.....
14 feet 1 inch	.....	.....	Sludge	.....
15 feet 1 inch	.....	145	.....	.....
15 feet 4 inches	.....	135	.....	.....
15 feet 6 inches	.....	Sludge	.....	.....
15 feet 6 inches	.....	.....	.....	135
15 feet 7 inches	.....	.....	.....	150
15 feet 9 inches	.....	.....	.....	Sludge

Bacteria.—It was found at Columbus that in the smaller basins the percentage removal of bacteria approximated that of total suspended matter. In the larger basins this seemed to be true at times. But on other occasions growths of certain types of bacteria developed to such an extent as to completely disguise the fact that many bacteria, attached to suspended particles, must have been carried to the bottom of the tank. So far as the author knows, these bacterial growths are not related to disease germs, but are incidental to decomposition steps, as certain types of bacteria here find an exceedingly favorable environment for development.

Organic Matter.—The removal of total organic matter ranges n complete sedimentation from about 30 to 35 per cent., or about one-half that of the total suspended matter. At the Lawrence station this figure was about 33 per cent., as given in the Massachusetts State Board of Health Report for 1908, page 454. But it is to be stated that the improvement in the stability or deoxygenating power of sewage due to sedimentation is somewhat less than indicated by the percentage removal of total organic matter, according to ordinary laboratory procedures. This was first clearly pointed out by Mr. Clarence B. Hoover in an article in *Engineering News* of March 16, 1911. With the large septic tanks at Columbus he found that the percentage purification was 35 as measured by the oxygen consumed from permanganate, but only 28 as measured by the actual bacterial consumption of atmospheric oxygen. This means, of course, that in proportion to their weight, the larger particles of suspended matter contain less putrescible matter readily undergoing bacterial decomposition than is the case of the more finely divided particles. Similar data are reported by Dr. Lederer of the Chicago testing station, as stated in Chapter I, page 43, except that these observations were not related to septicization.

Fats.—At Columbus it was found that 50 per cent. of the fats could be removed, while at Plainfield this figure is reported by Mr. Lanphear as 32 per cent.

Utility.—As to the needs and the comparative efficiency of sedimentation as related to filters, information is not clearly crystallized. Messrs. Winslow and Phelps speak of screening alone as affording sufficient preparation for sprinkling filters, as noted in their paper before the Boston Society of Civil Engi-

neers, in the *Journal of the Association of Engineering Societies*, Vol. XL, 1908, page 39. On the other hand, Mr. Rudolph Hering has taken the position of advocating as much clarification as feasible for the preliminary treatment of sewage to be applied to coarse-grain filters. His comments as applied to the Reading experiences are to be found in the *Engineering Record* of Sept. 10, 1910. With other types of filters similar discrepancies of views prevail, as will be described later.

Economical Limits.—Theoretically the economical limits of plain sedimentation may be summed up along substantially parallel lines to the rating which the process has received in connection with water treatment. Obviously plain sedimentation should not be carried beyond the point where the remaining sediment can be disposed of more cheaply and just as satisfactorily by other means. Until that limit is reached, sedimentation is desirable. But it should not be carried beyond that limit. Where that limit comes is a difficult matter to state in precise terms. It undoubtedly varies for different local conditions.

It is practicable to remove from ordinary sewage about 60 to 65 per cent. of the total suspended matters, or about 85 to 95 per cent. of the total settling solids. Where thorough treatment is required this degree of sedimentation is ordinarily desirable. For clarification purposes alone, in connection with dilution, this limit is not always necessary.

As to the removal of organic matter, sedimentation has its limitations owing to the fact that so much of the unstable organic matter is either in solution or in a state of colloidal suspension. It is probably safe to say that the removal of the coarse suspended matters should ordinarily control the practical limits to which this process is carried. About 25 to 30 per cent. of the unstable organic matter will then be removed incidentally.

INFLUENCE OF AGE AND STRENGTH OF SEWAGE

The fresher a sewage is and the nearer the sedimentation basins are to the point of its origin, the greater will be the percentage removal of the impurities, especially the suspended matter. As sewage increases in age, suspended matters naturally become comminuted and have a subsiding value which is less than before their disintegration begins.

Within certain limits it appears as in Table 61 that the more dilute the sewage is the smaller will be the percentage removal of suspended matters. This general comment is made from inspection of comparative data obtained in Europe and America. Just why this is so is not fully understood, but it appears to be associated in some measure with coalescence as related to colloidal and other finely divided matters.

If sedimentation could be practiced at various points along the collecting system of sewers and with a minimum amount of diluting water, the process would no doubt assume a different aspect for some projects than it does from the evidence hitherto obtained.

INFLUENCE OF TEMPERATURE

As Mr. Hazen pointed out in the paper already quoted from at length, temperature is a factor in connection with sedimentation. It is not so important as appears at first sight because it modifies the critical subsiding velocity of only a comparatively small percentage of particles. Most of the settling solids will settle regardless of the influence of temperature; that is, they will settle during either winter or summer conditions. On the other hand, the majority of the colloidal or so-called non-settling solids will not subside even under conditions of highest temperture during summer. Nevertheless, this factor is of some importance as mentoned by most writers who have gone carefully into the subject. In Mr. Kimberly's translation of Dr. Schmeitzner's book, reference on page 67 is made to rather significant experiences obtained by Schmidt and Opplen. These comments, of course, refer more to open than to covered tanks.

In some instances stratification of the liquid in the sedimentation chamber becomes of importance. When this occurs short circuiting of the flow and other queer results may obtain. However, it is possible under some circumstances for stratification and temperature conditions to influence the results obtained in rather a striking way. In water works practice, for instance, Mr. Wynkoop Kiersted states that some deep basins are decidedly preferable to shallow ones, as noted by his experiences at Kansas City. He attributes this in a considerable measure to the influence of thermal stratification. (See the *Engineering Record* of Feb. 17, 1912, page 188.)

TYPES OF TANKS AND BASINS

There are five general types of sedimentation basins, as follows:

(a) Horizontal flat-bottomed tanks, operated on the fill-and-draw principle.

(b) Horizontal flat-bottomed tanks, operated on the continuous longitudinal displacement principle.

(c) Horizontal hopper-bottomed tanks, operated on the continuous longitudinal displacement principle.

(d) Vertical circular tanks with hopper bottoms operated with a radial flow from a central inlet to a peripheral outlet.

(e) Vertical circular or rectangular tanks with hopper bottoms, operated on the upward displacement principle.

Of these general types the first is almost obsolete, except where used in connection with the storing of sewage as at Brockton, Framingham, Clinton and Pittsfield, Mass. The original tanks at London, England, were built on this basis, but were quite soon changed to the continuous displacement schedule. The same is true of most water works basins unless they are used for storage purposes.

Covers have not been provided ordinarily for sewage clarification basins. There are some exceptions to this rule, partly explained by the severity of winter weather, as at Saratoga, N. Y., and partly for the sake of hiding the sewage from view. In connection with septicization, covers have also been used to some extent to minimize odors in the neighborhood, due to escaping gases.

The design of these tanks, as well as the choice of type, has not followed any clearly defined lines, and there is considerable room for improvement. Tanks or basins naturally have to conform to a greater or less extent to the local conditions affecting construction. They should be designed with especial reference first to clarification and second to the removal of sludge. Where the influent is not well screened care should be given to the removal of scum, especially if the raw sewage is in a fresh uncomminuted condition. Grease removal is also a factor under some conditions.

FEATURES OF DESIGN FOR CLARIFICATION PURPOSES

We will speak first of horizontal tanks as distinguished from vertical ones. This matter has had so many factors associated

with it that data are meager for indicating the limiting dimensions for plain sedimentation, as distinguished from chemical precipitation or septic tanks. The main points available are as follows:

Capacity.—A period of from 2.5 to 4 hours for the average flow of sewage is reasonably advantageous for purposes of clarification. Septic tanks, built two or six times as large as this, have other purposes to serve, namely, the storage of sludge and the guarding against gas-lifted sludge particles in the final effluent. In the Philadelphia report of 1911 Mr. Webster states that 3.5 hours' nominal flow in a baffled tank gave a removal of about two-thirds of the total suspended solids in crude sewage and that this removal was not increased proportionally in a larger size of tank. At the same time it is to be borne in mind that European data with stronger sewages and experiences with chemical precipitation do not indicate it to be wise to make the capacity too small. For weak sewages the capacities should be larger than for strong sewages. In other words, they should have a capacity of more rather than less than 2.5 hours' average flow of sewage. For the effluent of coarse-grained filters this size may be cut in two.

Average Velocity.—So little regard has been paid in America to velocities, and the baffling of sedimentation basins has been so poor, that we have little experience from practice to serve as a guide. Theoretically it appears that the lineal velocity should be within the limits of 4 to 12 millimeters, equal to about 0.17 to 0.50 inch per second. Most American tanks have provided much lower velocities than this, but their comparatively great width and small length have perhaps not made them especially useful examples to follow. A few of the later tanks have been baffled, and velocities at Columbus and Baltimore approach the limits above given. These limits in velocities are the best that now can be suggested. Higher velocities seem inadvisable, and the lower limit is preferable to the upper.

On page 19 of his paper before the Boston Society of Civil Engineers Mr. Saville gives 5 millimeters or 0.20 inch per second as the normal velocity of flow in horizontal Imhoff tanks in the Emscher district.

Bottom Velocities.—These double-decked settling tanks, as will be discussed in some detail later, probably have considerable advantage owing to the automatic removal of the sediment on

the bottom. As a result of such removal there are smaller accumulations just above the bottom of those matters having a subsiding value approaching or just above that necessary to cause their permanent deposit. When increased flows come, there is probably less of a scouring action along the bottom of these double-decked tanks than in the case of one-story basins. Due weight should be given to this aspect of the case.

Maximum Velocities.—It is probably not wise with American sewages of ordinary strength to make the velocities as high as they frequently are in Europe. Particularly is it necessary to consider maximum velocities at certain hours of the day, especially with small plants. They ought not to exceed about 12 millimeters or 0.5 inch per second and preferably should be lower.

Influence of Viscosity.—In Mr. Hazen's foregoing discussion attention is called to the fact that a particle having an hydraulic value of about 8 millimeters or 0.32 inch per second marks the limit above which friction controls and the hydraulic value varies with the square of the diameter of the particle; and below which the viscosity of the water comes more and more into control. As particles decrease in size a limit is reached where viscosity causes the subsiding value to vary with the square root of the particle. This suggests that so far as we know about the theory of subsidence the lineal velocities above stated are within reasonable range of economical limits.

Baffles.—Basins are provided with baffles or flow regulators in order to accomplish one of two results. One is to produce a velocity of flow so as to prevent deposition of suspended matters and to bring about a thorough mixing of two or more streams, such as is frequently necessary when applying chemical solutions to water or sewage. The other is to guard against dead spaces, which cause the practical effect of the basin, as an aid to subsidence, to be no greater than would be obtained with a well-baffled basin of smaller size. Baffles are used, therefore, to accomplish diametrically opposite results, namely, to promote mixing or to prevent deposition on the one hand, and to facilitate sedimentation on the other.

The use of baffles to facilitate subsidence is undoubtedly a feature which can be used to greater advantage in the United States, under some circumstances, than hitherto has been the practice. Baffles are most advantageously used, as a general proposition, when they make the velocity of the entire flow as

nearly equal as possible to that obtained by dividing the volume of water passed through in a given length of time by the cross-section of the basin. In brief, they promote the completeness of displacement. Baffling to a greater degree than this, except in cases where the mean velocity is much less than the critical velocity, commences to retard deposition by increasing the velocity and making the basin approach a mixing compartment. On the other hand, baffling to a less degree than this allows some of the liquid to reach the outlet too quickly. The lessened clarification of this portion is not likely to be offset by mixture with the remainder of the effluent that passes through at a lower velocity than is required for the subsidence of particles which it is practicable to remove.

Vertical baffles sometimes are needed to guard against dead spaces and to minimize the effect of thermal stratification such as might otherwise result in sewage passing to the outlet in much less time than should be the case. How far they are of aid at the bottom, in guarding against the scouring of sediment at times of high rates of flow is not very well understood. Top baffles extending perhaps 10 inches beneath the surface are used at a number of places. Probably their action is better explained by regarding them as scumboards to hold back floating matter than as baffles to promote the efficiency of sedimentation.

Difficulties of Baffling.—It is not a simple matter effectively to design baffles for practical use. In the first place, it is not feasible to control the flow of water unless some head is utilized. This is difficult to secure in many instances. Again, when the flow is controlled it means that rearrangements in its direction and intensity come to the front. Unless much care is exercised baffles may not only do no good, but they may actually tend to defeat the purpose sought. While it is not difficult to improve upon most of the present designs, it is true that more studies are needed as to the practical aspects of baffles. Ease of removal of sludge should be kept in mind in arranging baffles to lessen objectionable currents.

Relation of Length, Width and Depth.—Mr. Kimberly, in his translation of Dr. Schmeitzner's book, page 75, states that the width to length should be within the range of 1 to 6 and 1 to 10. Additional division walls running lengthwise of the settling tanks have frequently been added to European plants with well defined improvements in the results obtained. Then comes the question

of making each compartment receive its share of the flow and no more.

As to the relation between length and depth, there is a wide difference between theory and practice in this country. Theoretically the shallower a basin is the more favorable is the sedimentation under some circumstances. This is exploited at much length by Mr. Hazen in the paper quoted from above. It is not a factor, however, with those particles which will or will not subside in any kind of a basin. It is related to some of the features stated above as to the influence of temperature. Furthermore, the expense and necessity of frequent cleaning limit the practicability of very shallow basins.

The Reading settling tank is some 16 feet in depth and the results obtained from it have been satisfactory on the whole as regards clarification. Furthermore, it is economical for the local conditions. Until we have more information available it is not likely that much added expense for construction will be undertaken for the sake of making tanks from 3 to 8 feet in depth as is sometimes found in Europe. Convection currents due to temperature changes, vortexual motions resulting from the entering velocity, and the fact that many coarse solids will settle in any reasonably large tank, are ample explanation why theory will have to become more explicit before marked changes in practice are likely to occur. It is of interest here to note the data of Table 59 obtained with the 200-foot tank at the Columbus testing station.

Tanks in Series or Parallel.—Within reasonable limits, say for a length of flow of from 15 to 30 times the depth, tanks arranged in series have advantages that are well defined as distinguished from tanks arranged in parallel. It appears to the author that the benefit of a serial arrangement is related substantially to means for preventing the appearance in the effluent of the results of disturbance of sediment upon the bottom, due to the effect of occasional increasing velocities. In some instances tanks are of wider cross-section and therefore with lower velocities at the outlet than at the inlet end. In other instances baffles are arranged with the view to keep the sludge from moving readily toward the outlet end. When increased rates of flow occur, all of these arrangements tend to minimize the appearance in the effluent of particles which have once hit the bottom but have not become permanently located there.

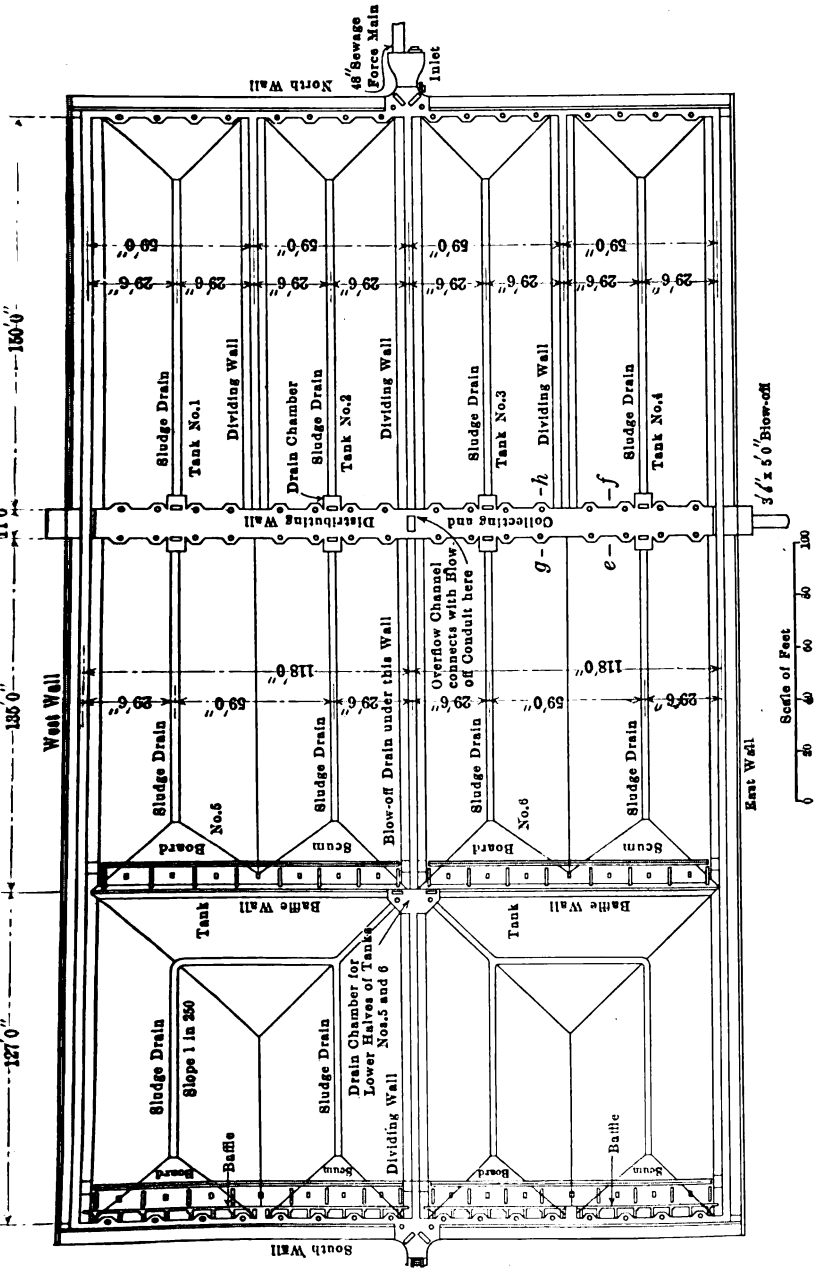


FIG. 24.—Plan and sections of settling or septic tanks, Columbus, O

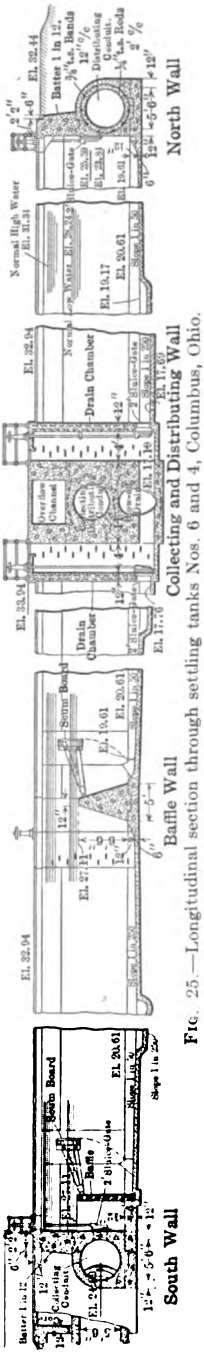


FIG. 25.—Longitudinal section through settling tanks Nos. 6 and 4, Columbus, Ohio.

In Mr. Kimberly's translation of Dr. Schmeitzner's book, page 71, this idea is brought out comparatively to show the results obtained at Sheffield and at Viersen. At the former there is no widening of the cross-section toward the outlet and the removal of suspended matter is given as only 49.3 per cent., whereas with three tanks in series at Viersen with progressive widening of the cross-section, the removal of suspended matter is 82 per cent.

If the automatic removal of sediment from the upper to the lower compartment through the connecting slot in double-decked tanks has the significance which appears perfectly feasible to the author, then the comparisons between these Sheffield and Viersen data may perhaps afford an explanation to a greater extent than hitherto realized as to the influence of bottom scouring velocities and the benefit of the double-decked tank in reducing its effect.

Inlet and Outlet Connections.—The most important feature in this connection is to deliver sewage to and receive it from substantially the full width or cross-section of the tank. If this is not done it tends to create dead spaces that are useless for sedimentation purposes. The entering velocity, if not checked, is liable to cause a surprisingly large amount of sewage to reach the outlet in a comparatively short time. In checking the velocities objectionable eddies may be created, however. Adjustable weirs afford probably the best means of regulation at both the inlet and outlet. Fig. 24 shows a plan of the Columbus settling tanks with inlets and outlets, comprising sluice gates spaced about 12 feet apart. In front of the outlet is a baffle and scum board. Fig. 25 shows some typical sections of these tanks. They are taken from

Mr. Gregory's paper before the American Society of Civil Engineers.

Fig. 26 shows the perforated pipe inlet connection at the

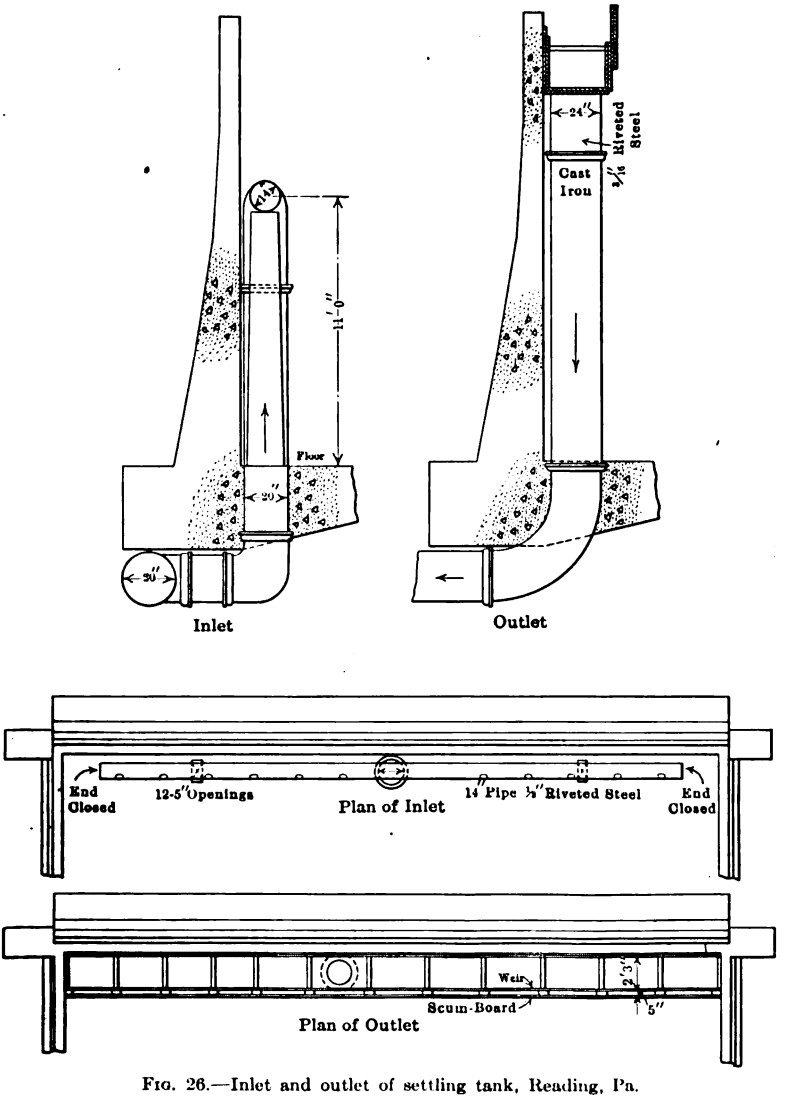


FIG. 26.—Inlet and outlet of settling tank, Reading, Pa.

Reading settling tank, with outlet weir and scum board. Perforated or slotted pipes are liable to give trouble from clogging when used for outlet connections.

It is not imperative that there should be an overflow for the entire width of the tank at either end, but theoretically this gives the best distribution throughout the width of the tank, within reasonable limits of expense.

It is highly important to prevent deposits in the inlet and outlet connections, as they will decompose and give off odors. Deposits are best prevented by ample velocities in well-rounded water ways.

VERTICAL TANKS

In America experiences with vertical tanks for purposes of clarification have been meager. Until quite recently experience was confined to a set of four vertical tanks of the so-called Dortmund type used in 1893 at the World's Fair in Chicago for purifying the sewage of the exposition grounds with the aid of chemical precipitation. Theoretically some advantages accrue to a tank in which sewage is applied at the bottom and the clarified effluent removed at the top. The settling of suspended matters seems to promote coalescence or massing together. This aids in the removal of the smaller particles. Many of the larger particles travel but little or no distance toward the overflow. In a certain sense there is something to support the suggestion that these upward-flow vertical settling tanks may be compared with sludge filters. While the main body of sewage does not pass through the entire mass of sludge, the clarification within certain limits is undoubtedly promoted by the actions which take place as the sewage rises through the falling precipitate.

With the introduction of coarse-grained filters and the attention given to means of removal from the final effluent of fairly coarse suspended matters, study was directed to various tanks other than the old flat-bottomed arrangements. It was not the economical aspects of the question that called this matter to the front again, but more particularly the means for cleaning the tanks readily without interrupting operations to a serious extent.

Still more recently the vertical tanks have attracted attention as a means of clarifying sewage whereby the sludge may be treated in ways other than in the old single-story septic tanks.

Industrial concerns have taken advantage of these methods to some extent and undoubtedly in the future these tanks are going to find a place for themselves in the field of municipal

sewage works. Brief descriptions will be given of available information.

World's Fair Tanks, 1893.—These tanks, four in number, were modeled after tanks designed by Mr. Karl Kinnebuehler at Dortmund, and were used as above stated in 1893 for treating the sewage from the various buildings of the exposition grounds. Such tanks are called by some the Roeckner-Rothe type. The plant is described by Messrs. Rafter and Baker on page 566 of their book and in *Engineering News* of Aug. 3, 1893. It is also

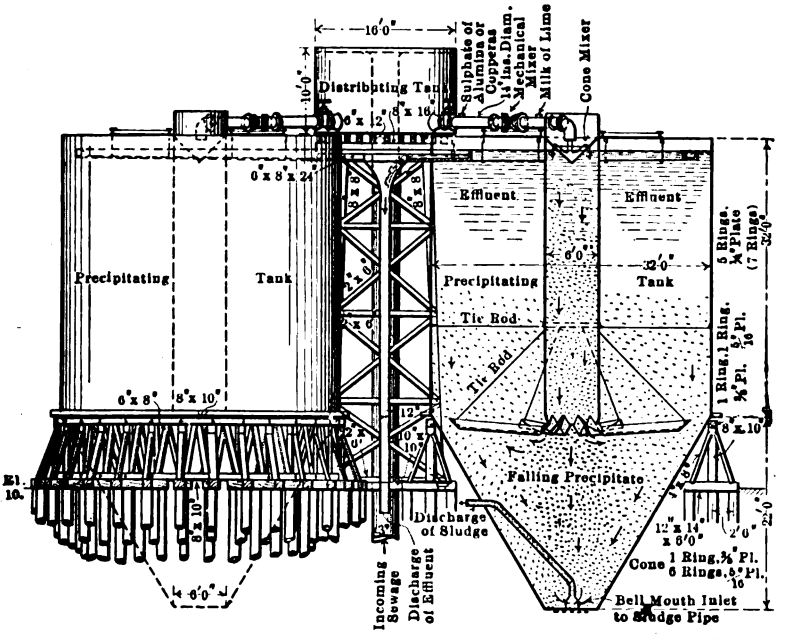


FIG. 27.—World's Fair tanks, Chicago, Ill.

described in detail by Mr. Hazen, who had charge of the operation of this plant, in the Massachusetts State Board of Health Report for 1893, page 597. Each of the four cylindrical iron tanks was 32 feet high, and 32 feet in diameter with conical bottoms, which in a height of 22 feet tapered in diameter from 32 to 6 feet. The total height of 54 feet gave a capacity to each tank of about 237,000 gallons up to the radial outlets about 18 inches below the top. The sewage entered a central standpipe at the top, 6 feet in diameter, and as shown in Fig. 27 passed downward to about the top of the conical portion of the tank. There deflectors aided

the distribution of the sewage so that it would flow fairly uniformly up to the several collecting troughs at the top.

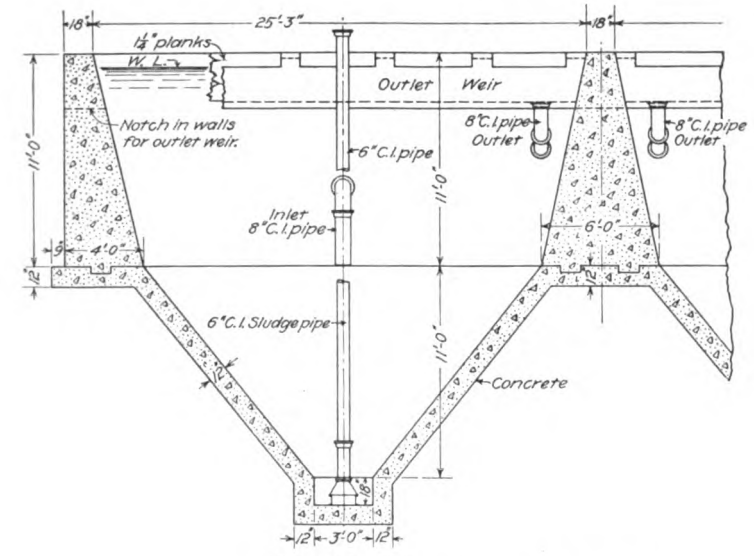
It was the difficulties encountered in the operation of this plant that are most worthy of attention. The sewage was delivered to the top by numerous Shone ejectors located at various points over the exposition grounds. The automatic shut-off appliances did not work satisfactorily and in consequence there were numerous occasions when air followed the sewage and delivered with much violence various mixtures of air and sewage. This can be appreciated best by the statement that glass windows in the roof, some 20 feet above the top of the vertical discharge pipe at the tanks, were broken by these "blows."

This feature was bothersome in numerous ways. It prevented the proper application of chemicals and caused more or less entrained air to appear in the sewage and rise to the top of the tank, thus interfering with sedimentation.

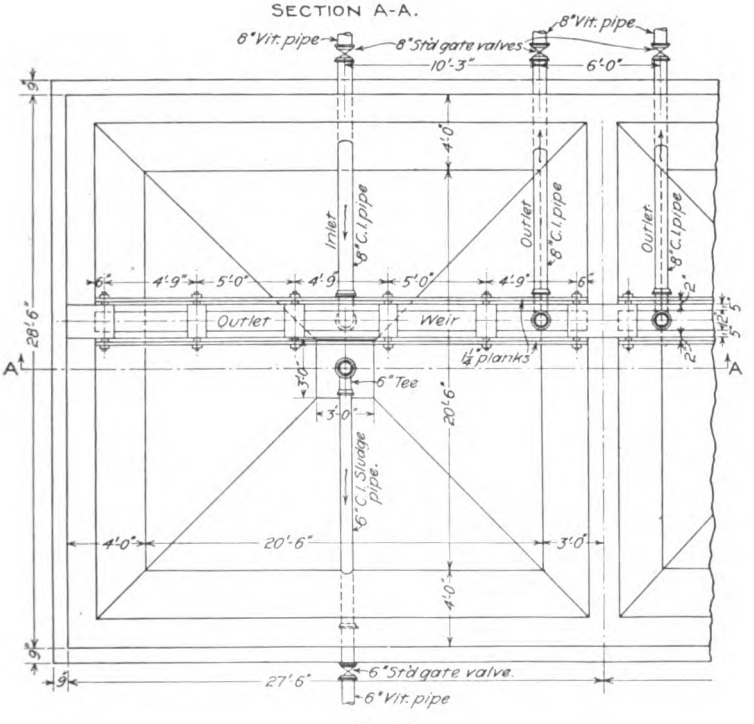
Another difficulty encountered was in the removal of deposits of sludge from the slopes of the conical bottom. The laps in the riveted plates increased the difficulty in having the sludge slide down to the sump at the bottom of the cone. At times the accumulations of sludge decomposed to an extent that interfered with the purpose of clarification. When the sludge on the bottom and sides of the tanks was cleaned out, and on other occasions at intervals of two or three days, its movement towards the sump was hastened by the aid of a heavy weight attached to a rope and pulled upward and downward over the slopes.

Kings Park, N. Y.—These tanks serve a population of about 4000 people at a large insane asylum on Long Island about 40 miles east of New York City. The works were designed by Messrs. Hering & Fuller and comprise two tanks modelled more or less after the tanks used by Mr. John D. Watson at Birmingham, England. For an average flow of about 400,000 gallons per day they have a total capacity of about 4 hours' flow. Their dimensions are 25.25 feet square, and 22.5 feet deep from flow line to sump. The inlet extends to about 9 feet below the surface. The effluent is removed by a central channel of concrete 12 inches wide and 18 inches deep, whose sides act as weirs over which the settled sewage flows in a thin film. Scum boards are placed about 2 inches in front of their outlet weirs.

Fig. 28 shows some of these details. The tanks seem to serve



SECTION A-A.



PLAN.

FIG. 28.—Plan and section of settling tanks, Kings Park, L. I.

well as clarifiers, although the upward displacement by the sewage flow is not so complete as might be. Messrs. Merritt and Co., of Camden, N. J., have recently provided multiple outlet weirs for tanks of this general type.

Barbour on Industrial Plants.—Mr. Barbour in a paper on the Disposal of Manufacturing Wastes before the State Engineering Society of Pennsylvania in 1909, gives valuable experiences which he has had with the clarification of industrial wastes. On page 441 of Vol. I of the *Journal of the Engineers Society of Central Pennsylvania* he speaks of vertical circular tanks in which the period for the upward passage of the liquid through the tank is 2.5 hours. The upward velocity of flow is stated as equivalent to about 3.6 feet per hour, equal to about 0.012 inch, or 0.3 millimeter per second. The paper is abstracted in *Engineering News* of June 17, 1909.

Gloversville, N. Y.—Messrs. Eddy and Vrooman designed settling tanks for the preliminary clarification of the sewage of Gloversville, N. Y. The contract was awarded in December, 1909, for the treatment works for this sewage which is quite highly impregnated with tannery wastes. In *Engineering News* of April 28, 1910, Mr. Vrooman gives a brief description of the vertical settling tanks. There are two of them, circular in form, with conical bottoms. The cylindrical part is 36 feet 4 inches in diameter at the top, 35 feet at the base and 31 feet deep. The conical bottom is approximately 18 feet deep. Each tank will contain about 48 feet in depth of sewage. The inlet trough connects with a 3-foot wooden pipe extending 31 feet down from the top of the tank and connecting with a distribution cone 18 feet 6 inches in diameter. Near the top of the tank are four troughs for the collection of the effluent. The capacity of these tanks in terms of average rate of flow is about 3.5 hours, but at the maximum rate of flow this period will be reduced to about 2 hours. At the average rate of flow the vertical velocity will be about 8.6 feet per hour, equal to about 0.03 inch, or 0.7 millimeter per second.

Emscher District.—In connection with Imhoff tanks velocities have been studied considerably by American engineers. With the strong sewage of the Emscher district it is the custom to make the capacity of the vertical tanks corresponding to from 0.5 to 1.5 hours' flow during the day. They are radial flow (or horizontal flow) tanks as distinguished from upward flow tanks.

In the former the sewage is ordinarily applied at the center, then it moves downward, passes under a baffle and flows upward to a circumferential outlet weir. The velocity is studied carefully with respect to the upward movement of the water after it has passed beneath the circumferential vertical baffle located a little nearer the center than the periphery of the tank. Mr. Saville in his paper before the Boston Society of Civil Engineers speaks of this upward velocity at all times as being less than 1 millimeter per second and with very weak sewages it has been found advisable at times to make it as small as 1/3 of a millimeter per second. These figures correspond to about 12 and 4 feet per hour, or 0.04 and 0.013 inch per second, respectively.

Chicago Sanitary District.—In the studies prepared under the direction of Mr. Wisner and included in the report made to the Chicago Sanitary District in October, 1911, some interesting comparisons are made of different tanks as described in *Engineering News* of Nov. 30, 1911, page 653. The nominal settling period is given as 4 hours for Dortmund tanks of the Gloversville type. With the Imhoff tanks of the horizontal-flow type, the nominal detention period is 3 hours. Where the sewage flow is about 200 gallons per capita this report gives the cost per capita of the Dortmund tank as about $0.84 and of the Imhoff tank $1.44. The latter is given the preference in connection with the advantages which it possesses for the removal and treatment of the sludge.

Speaking generally, the vertical tanks are capable of giving good clarification, but it is necessary to study carefully the arrangement of the inlet and outlet connections so as to avoid so far as practicable dead spaces due to the short circuiting of the liquid in its flow through the tank. With the single-story tanks a straight upward flow seems to be better, but where digestion chambers for the sludge are built beneath there are substantial construction advantages to the so-called radial flow tank for small units where it would be very expensive to build very deep structures. In all instances with sewages that contain matters likely to form scum, baffles or scum boards should be arranged to prevent floating matters passing into the effluent pipe.

The main advantage of vertical tanks is the ability to remove sludge by gravity and without the cost and annoyance of removing the supernatant liquid. Horizontal flow tanks with hopper

bottoms have recently come into competition with the vertical tanks.

DETAILS FOR SLUDGE REMOVAL

These details depend much upon the style of tank. For vertical tanks, it is feasible to secure by hydrostatic pressure a gravity flow of the sludge in the conical bottom to a sump at the apex and thence through an outlet pipe. These outlet pipes usually extend upward to within about 4 to 6 feet of the normal flow line. The weight of the superimposed sewage then forces the sludge through the outlet pipe to the desired point. The interruption in regular service is slight or *nil* and there is practically no removal of the overlying sewage.

In the older vertical tanks there is little doubt that the slopes were too flat. The Chicago experiences at the World's Fair in 1893 as described by Mr. Hazen are very pertinent in this regard. Even slopes of 45 degrees, where there are obstructions like overlapping plates, do not permit the sludge to move to the sump, but allow it to remain there in part while the sludge outlet pipe receives more or less fairly clear sewage from above. At King's Park the slope in the corners of the concrete tanks is 42 degrees with the horizontal and about 51 degrees on the faces midway between the corners. Care was taken to make the sloping surfaces smooth, and the sludge is removed quite successfully.

Mr. Barbour, in his Harrisburg paper above cited, states that in his experience the slopes should not vary from the vertical more than 30 degrees; that is, they should be at least 60 degrees from the horizontal. That experience was obtained with manufacturing wastes and not with municipal sewage.

Where sludge is not removed quite frequently it may become compacted so that the available hydrostatic pressure does not make the sludge slide from the sides to the sump. Thus a funnel-shaped opening through the sludge above the sump is produced and the clarified sewage reaches the sludge outlet pipe. A pipe laid on the bottom part way up the sloping floor for the introduction of water under pressure is well suited to meet this difficulty, by allowing the pressure water to stir up the sludge. Where hydrostatic pressure is small, aid may be obtained from the use of a hand-operated sludge pump.

Horizontal flow tanks have been provided in a few instances

in America with hopper-shaped bottoms to allow the sludge to be removed without draining off the overlying clarified sewage. In the *Engineering Record* of Aug. 27, 1910, a description is given of such a tank designed by Mr. Barbour for North Attleborough, Mass. The main features are shown in Fig. 29. It is in duplicate, with a total capacity of 100,000 gallons to provide sedimentation for a flow of 500,000 gallons daily.

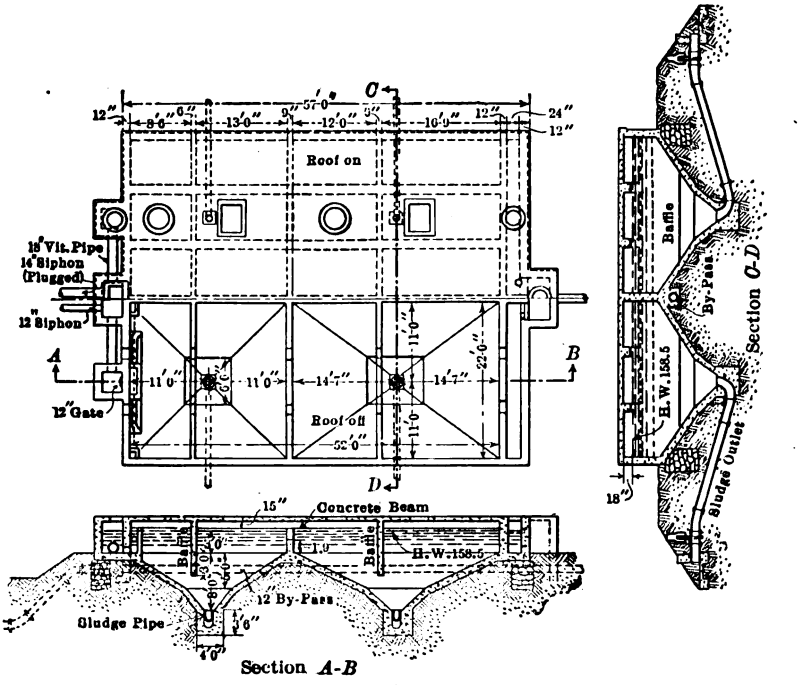


FIG. 29.—Plan and sections of settling tank, North Attleboro, Mass.

At Toronto, Ont., hopper-bottomed settling tanks are approaching completion in accordance with designs of Mr. John D. Watson of Birmingham, England. The main features are shown in Figs. 30 and 31, from a descriptive article in the *Engineering Record* of Mar. 18, 1911.

In Imhoff tanks, current practice is to make the slopes of the sedimentation compartment 1.2 vertical to 1.0 horizontal, giving a slope of a little more than 50 degrees from the horizontal. Some of them have slopes of 1.5 to 1.0 horizontal. It is probable that some sticky matters will adhere to the slopes regardless of

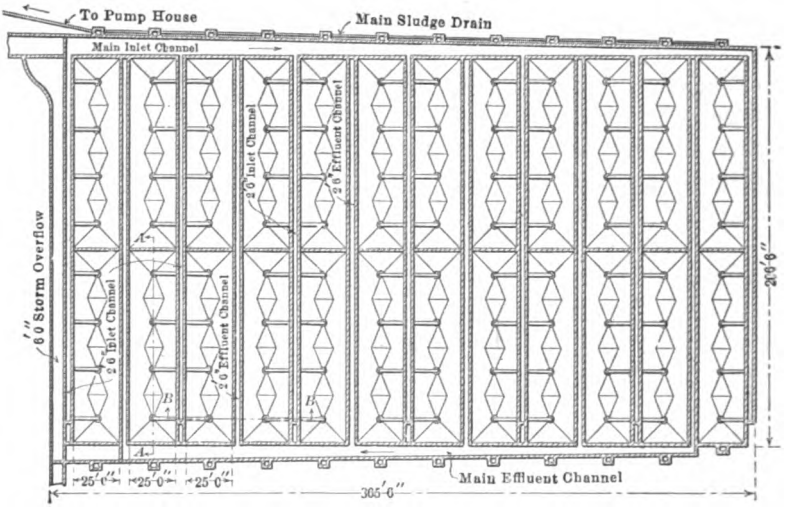


FIG. 30.—Plan of settling tanks, Toronto, Ont.

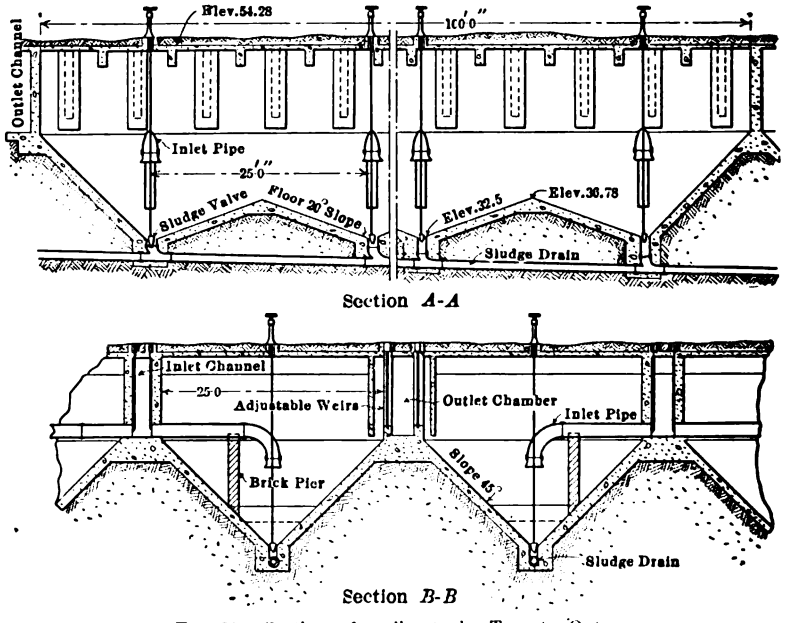


FIG. 31.—Sections of settling tanks, Toronto, Ont.

the angle and it is best to arrange some means for removing these deposits from time to time.

While it is possible with hopper-bottomed tanks to free them of sludge when in regular operation, two tanks are generally preferable to one, on account of repairs or other operations making it necessary to put a tank out of service. With flat-bottomed tanks it is necessary to put a tank out of service during cleaning. This necessitates a sufficient number of units so that with one tank out of service for cleaning the others will give fairly satisfactory service.

At Reading, where the present plant includes but a single preliminary sedimentation tank, there were unusual reasons for so doing, one being the urgent necessity of economy and another the desirability of utilizing existing structures. It was the recommendation of the author to by-pass this settling tank through a cast-iron pipe, so that sewage could be delivered from the force main to the filters at times of cleaning the settling tank. This was not done, however, and in consequence at times of cleaning all of the sewage is discharged into the river at the pumping station, while the clarified sewage in the tank is drained to an adjoining creek.

With flat-bottomed tanks, care should be given to provide means for removing fairly clear sewage lying above the sludge deposit. There are two ways of proceeding in this regard. One is by the use of a floating outlet pipe whereby the contents of the tank are removed from the surface. The other is to use movable weirs. The sewage so removed is preferably delivered to another tank.

The old precipitation tanks of England and some of the American tanks were built with fairly flat bottoms. The slope in many cases was 1 to 80 or 1 to 100. This slope gives reasonable service for thin watery sludge, but is bothersome where the sludge is fairly dense. A slope of 1 to 50 for the floors is better and within certain limits it is preferable to make it still steeper.

Speaking generally, sludge outlet pipes should not be less than 8 inches in diameter. They should be larger, of course, for large tanks. Sludge drains should have steeper slopes than drains for water or sewage. Thin sludge, say with 95 per cent. water, is considered in Germany to require for its removal after draining off the sewage a slope of at least 1 to 100. One to 80 is better. Where the water content becomes as low as 85 per cent. the slope

should be as much as 1 to 50. In removing sludge which has been septicized, as will be mentioned again later, the slopes to the drains should be at least 1 to 30 and it would probably be helpful to make them as steep as 1 to 20.

Closed drains or pipe should be freed of sludge after use, otherwise trouble may follow from clogging. Accessible open drains where practicable are preferable to closed pipes or conduits.

SLUDGE REMOVAL DEVICES

In America there has been no experience with mechanical appliances such as dredges or mechanically-driven scrapers to push the sludge to a sump. Arrangements of this sort are to be found in Europe at some of the larger plants, but information does not seem to be very definitely crystallized as to their advantages.

Where flat-bottomed tanks are used the sludge is delivered to sumps with the aid of pushers and in some cases more or less flushing with pressure water from a hose or from the unsettled sewage. The slopes above given do not allow the sludge to flow out and leave a clean tank without flushing.

In this country the present tendency is to use two-story tanks in which the sludge passes automatically to a sludge-digestion chamber below.

QUANTITY OF SLUDGE

The sludge or the solid deposit produced on the bottom of settling tanks brings to the front one of the most difficult problems to be dealt with in the field of sewage disposal. Recent experience affords valuable information as to handling this question. We shall attempt to record briefly some of the more essential facts now available and to point out the marked differences that occur in the quantity and quality of sludge obtained in the treatment of different sewages.

Grit chambers, when dealing with the flow of combined sewers, ordinarily retain from about 6 to 12 cubic feet of grit or mineral matter per million gallons of sewage on an average. If this is separated under the conditions recommended in this chapter, it may be disposed of satisfactorily at some convenient dump.

There remains, however, the major portion of the settling solids to be dealt with as a deposit in settling tanks. In some measure present data for the flow of combined sewers deal with an uncertain quantity of grit, which properly should be excluded from settling basins.

Controlling Factors.—The amount of sludge produced by plain sedimentation depends upon the following:

1. Quantity of the suspended matter in the unsettled sewage, particularly the settling solids.
2. Efficiency of plain sedimentation.
3. Per cent. of water in the sludge as removed.

Varying degrees of compactness, of quality of sludge and of specific gravity, together with some other varying factors associated more particularly with combined sewers and trade wastes, lead to results which are somewhat difficult to classify at the present time.

Speaking generally, for all sewage disposal projects a liberal allowance should be made for the quantity of sludge to be treated. Data from practical accomplishments under more or less similar conditions elsewhere should be studied, as it is not a simple matter to make proper theoretical deductions for some problems of this type. Experience and experiment, however, have done much in the last few years to advance our knowledge.

Methods of Measurements.—The amount of sludge produced is ordinarily expressed in cubic yards per million gallons based upon measurements of the sludge in place. The elevation of the surface of the sludge may be noted fairly accurately in several ways. With large tanks it is frequently the custom to lower a metal plate attached to a rod and note its position when it ceases to sink. Another method is to lower a tube either of metal or glass through which is passed a wire attached to a stopper. The tube is then lowered vertically to as near the bottom as practicable and the stopper is pulled in place, thereby allowing an approximation to be made of the elevation of the sludge. Mr. Chase has suggested another method as mentioned in this chapter in describing the data in Table 61.

Owing to the fact that in the removal of sludge from flat-bottomed tanks, it is not feasible to separate all the overlying sewage from the sludge, the tendency is for these measurements to be too small. In large works after the sludge is removed it is frequently resettled in another tank and the fairly clear super-

natant liquid returned to the main tanks for further treatment.

A check on the volume of sludge is afforded at some plants through opportunity to make measurements in sludge beds or tanks, or in barges or other containers used for transportation. Where sludge pressing or drying is practiced opportunity is also afforded for securing a check upon the measurement.

Quantity of Sludge by Computation.—At some plants, and particularly at testing stations where sampling schedules are carried out on a basis to give quite representative analyses of influent and effluent, it is possible within certain limits to compute the weight of deposited solids as the difference between the solids in the influent and effluent of the settling tanks. Knowing the volume of sewage treated, this gives a means of estimating the weight of sludge of an assumed percentage of water content. Such computations, however, should be checked with experiences obtained under more or less similar conditions elsewhere. Even in test plants, such results have not always been in harmony with the computed solids determined from well mixed representative samples of the sludge. Difficulties of sampling occur in this regard, particularly in large tanks. At or near the influent end the deposits are coarser and more granular than is the more finely divided, greasy and watery material found near the outlet end. Moreover, the organic content and specific gravity vary within quite wide limits, particularly with the flow of combined sewers.

Organic Content.—This varies considerably as has just been stated. The practical significance of this variation is perhaps best appreciated from noting the varying amounts of gasification and liquefaction in connection with septicization as described in the next chapter. The loss on ignition is not a very satisfactory index of the organic content, as it includes the volatilization of some mineral matters. Furthermore, it does not differentiate either as to the size, physical character or degree of stability of the true organic substances.

At the Philadelphia testing station where the sewage was from separate sewers receiving considerable manufacturing wastes, the loss on ignition in the sludge of plain settling basins was about 50 per cent.

With the plain sedimentation basins tested at Columbus the percentage of volatile matter in the sludge was found to be about 40 per cent.

At Gloversville the loss on ignition in the sludge from plain settling basins is recorded as about 54 per cent. These results were influenced no doubt by the tannery wastes in the local sewage.

Percentage of Water.—This varies considerably in the sludge samples as removed from different settling basins. Recently it has been the custom at several places to express the results as the volume of sludge containing 90 per cent. of water. This is a helpful custom, although for vertical tanks it would probably be more nearly correct to use 95 per cent. of water. In properly designed vertical tanks, or horizontal tanks with hopper bottoms, where the sludge is removed by hydrostatic pressure, there is practically no mixing of the sludge with the overlying water as is apt to be the case with flat-bottomed tanks. In some of the latter, however, the sludge shows less than 90 per cent. of water.

Specific Gravity.—This varies considerably according to the proportion of mineral matter, grease and entrained gases, etc. The author has spent much time in investigating the subject, but without satisfactory conclusions. For 90 per cent. of water, the sludge obtained from the flow of separate sewers was taken at Philadelphia as of a specific gravity of 1.02. At Gloversville with a sewage containing grit and tannery wastes, the corresponding figure was 1.06. For ordinary sewages from combined sewers perhaps a figure of 1.04 is more correct.

Weight of Dry Sludge.—In Table 15 of Chapter I will be found the approximate weights of dry suspended matter in various municipal sewages. The proportion of it that will subside may be taken for present purposes as 70 per cent. This establishes the weight of dry solids that may be expected in the sludge of plain sedimentation tanks. Bearing in mind that one part per million means 8.34 pounds per million gallons, it is a simple matter to compute the weight of wet sludge of known percentage of water corresponding to different parts of suspended matter removed. For convenience reference may be made to Table 63 for tons (2000 pounds) of sludge for different quantities of dry solids removed with 90 and 95 per cent. of water, corresponding to the quantity of water ordinarily to be expected with flat-bottomed and hopper-bottomed tanks, respectively.

TABLE 63.—WEIGHT OF UNDECOMPOSED SLUDGE PER MILLION GALLONS CORRESPONDING TO DIFFERENT QUANTITIES OF SOLID MATTERS REMOVED BY PLAIN SEDIMENTATION

Parts per million of dry solids deposited	Tons of wet sludge	
	95 per cent. water	90 per cent. water
50	4.2	2.1
60	5.0	2.5
70	5.8	2.9
80	6.7	3.3
90	7.5	3.7
100	8.3	4.2
110	9.2	4.6
120	10.0	5.0
130	10.8	5.4
140	11.7	5.8
150	12.5	6.2
160	13.3	6.7
170	14.2	7.1
180	15.0	7.5
190	15.8	7.9
200	16.7	8.3
225	18.7	9.4
250	20.8	10.4

Relation of Weight to Water Content.—Changes in the weight of sludge due to changes in the per cent. of water content may be accurately computed from the formula on page 23 of Chapter I.

Relation of Weight to Volume.—This depends upon the specific gravity which as just stated on page 445 varies with different types of sewages. More study is needed on this subject, but for purposes of approximate estimates use may be made of the range of figures in Table 64. Columns A, B and C are based on specific gravities for 90 per cent. water of 1.02, 1.04 and 1.06, respectively.

TABLE 64.—APPROXIMATE WEIGHT IN POUNDS OF ONE CUBIC YARD OF WET UNDECOMPOSED SLUDGE OF DIFFERENT PERCENTAGES OF WATER

Per cent. of water	A	B	C
100	1685	1685	1685
95	1700	1720	1735
90	1720	1755	1785
85	1735	1785	1835
80	1755	1820	1905

The data of the foregoing table are restated in Table 65 as a matter of convenience to show the volume of one ton of sludge, according to different percentages of water and different specific gravities.

TABLE 65.—APPROXIMATE VOLUME IN CUBIC YARDS OF ONE TON OF 2000 POUNDS OF WET UNDECOMPOSED SLUDGE OF DIFFERENT PERCENTAGES OF WATER

Per cent. of water	A	B	C
100	0.84	0.84	0.84
95	0.85	0.86	0.87
90	0.86	0.88	0.89
85	0.87	0.89	0.92
80	0.88	0.91	0.95

Diagrams prepared from these and similar data are of assistance in showing the relation of sludge of varying weights and volumes as found with different removals of dry matter from the sewage.

The influence of septicization is not shown in the above tables.

FREQUENCY OF CLEANING

Practice has varied materially with respect to cleaning plain sedimentation basins. For many years it was the practice to clean the basins only when they became so overloaded with sludge,

or when gasification so lifted the sludge, that objectionable amounts of suspended matter were found in the effluent. Naturally this has varied much with the season of the year, with the character of the sewage and with the facilities for the storage of sludge within the sedimentation basins.

At Columbus gasification occurred in from 8 to 17 days. In winter the tanks were allowed to go 38 days without cleaning. At Reading with a deep tank, the needed cleaning intervals due to gas ebullition have ranged from about one month in summer to three months in winter, as measured by the requirements of keeping suspended matter from appearing in objectionable amounts in the effluent. At Worcester where the sewage contains acid wastes, Messrs. Eddy and Fales found that the plain sedimentation tanks should be cleaned at intervals of 4 to 8 weeks.

Mr. Kimberly in his translation of Dr. Schmeitzner's book, page 78, states that at Hanover, Germany, during the summer the tanks are cleaned every 2 or 3 days, although Bredtschneider indicates that cleaning is not necessary oftener than perhaps every 4 weeks or when solid masses of sludge appear in the effluent. At the same time mention is made of the importance of preventing septicization from becoming established. Elsner gives a general cleaning interval of 3 to 7 days in summer and 8 to 12 days in winter.

In his paper before the Boston Society of Civil Engineers, Mr. Saville in speaking of sedimentation chambers mentioned the desirability of removing the small amounts of sludge which stick even to the steep slopes of the sedimentation compartment of Imhoff tanks. He speaks of this cleaning at intervals of 10 days to 2 weeks as being done with a rubber straight-edge fixed to the end of a pole.

The thoroughness of cleaning and the necessity of removing small deposits as mentioned by Mr. Saville, is now considered to be of much more significance than was the case a short time ago. It relates to the seeding of certain types of bacteria and the establishment of enzymes which may have a far more reaching effect than was considered hitherto. From this standpoint, cleaning and flushing of the sediment from sedimentation tanks should be done thoroughly unless it is the intention to promote rather than to prevent septicization.

TREATMENT AND DISPOSAL OF SLUDGE

This question has been discussed so fully from both the European and American standpoints in a recently published book by Mr. Kenneth Allen, that we shall confine ourselves to the principal essentials of the problem.

Sludge disposal is a bothersome subject for two reasons, as follows:

1. It contains so much organic matter of an unstable nature that decomposition begins quite promptly. It is liable to produce offensive odors during decomposition unless they are properly controlled.

2. The large quantity of water makes it expensive or difficult to transport or to treat and the removal of this water involves considerable expense.

The utilization of sludge on account of its fertilizing properties or for the sake of extracting grease does not give promise under any ordinary circumstances of commercial success. Nitrogen, phosphorous and grease are present in substantial quantities, as explained in Chapter I. But the fact remains that the cost of separating these constituents from ordinary municipal sewage sludge is greater than the proceeds from their sale.

In America the disposal of sludge relates in part to experience with some methods upon which our knowledge is fairly definite from use at numerous places; in part to methods that have been tried in practice to but a limited extent; and partly to still other methods that have either been employed on a small scale or studied with respect to European experiences.

Practical developments in America with sludge disposal are confined mostly to the following methods:

1. Septicization is employed at about 200 or roughly 60 per cent. of the municipal sewage plants in this country in which sedimentation forms a part of the process. Experience with these and numerous institutional plants embodies such a wide field that this subject is treated separately in Chapter XIV. When carefully applied it is considered the best available method for most cases.

2. Sludge pressing has been confined in practice almost wholly to chemical precipitation plants. But as the Worcester and Providence plants embody this feature, considerable knowledge as to the significance of the sludge question, particularly as to its

cost, has been obtained from them. This will be described in Chapter XV. To a limited extent the sludge of plain sedimentation basins has been filter pressed.

3. The application of sludge to land, particularly to sludge beds, whereby the liquid content of the sludge is removed in part by filtration and in part by evaporation, constitutes the prevailing method for the disposal of sludge in inland cities.

4. Disposal of sludge by dilution or dispersion in water is a well established custom along the seaboard and in the vicinity of some large rivers and lakes.

In a separate group from the above come methods which have been tried at a few places and which are seriously considered at the present for use at some well-known plants. They are as follows:

5. *Lagooning.*—The construction of dikes to permit of the application of wet sludge to a much greater depth than ordinarily practised with air drying, and with more or less incidental septicization, is the method followed at Reading since 1908.

6. *Filling.*—Filling of low waste land with the sludge mixed with other refuse is the method suggested at a number of places, the principal one being Toronto.

7. *Digestion Tanks.*—This is a somewhat intermediate method between septicization as ordinarily practised and the custom of lagooning as practised at Reading. This is the method adopted at Baltimore.

8. *Open Trenching.*—This method in some places has been used as an aid in the application of sludge to land.

9. *Covered Trenches.*—This has been tried at Kings Park, Long Island.

Several other methods have been studied, but about which practical information from American experiences is meager. In this group are the following:

10. Incineration.
11. Destructive distillation.
12. Mechanical drying.
13. Use as filler for fertilizers after drying.

SLUDGE PRESSING

This was tried by Mr. Eddy at Worcester. It was found to cost about one-third more to press the sludge from plain sedi-

mentation tanks than an equal amount of the sludge from the chemical precipitation process. This was due to the need of adding much more lime to the sludge; up to 100 pounds per million gallons. Cost data on sludge pressing at Providence and Worcester will be found in Chapter XV. The broad question of handling sewage solids is well reviewed by Messrs. Eddy and Fales, as already stated, in their Boston paper of 1906.

SLUDGE BEDS

In Massachusetts there are a number of small settling tanks, holding from 0.5 to 3.0 hours' flow, in which the sewage is freed from the coarser solids preparatory to sand filtration. There are also several of the larger sand filtration plants which deal with sludge obtained from the bottom of storage reservoirs. The purpose of these reservoirs as already mentioned is to store the night flow so that pumps may be operated during the day only. The last portions pumped are quite "heavy sewage," but weak fresh sludge.

The general practice in New England is to apply the heavy sewage or weak sludge either to specially prepared sand beds or to certain of the regular sand beds devoted to this purpose.

In the Massachusetts State Board of Health Report for 1903 this subject is briefly mentioned in connection with each of the principal sewage disposal plants in that State. The results of applying the sludge vary according to the porosity of the beds, the ease with which they are operated and the climatic conditions. In some instances results are quite satisfactory, but in others offensive odors are noted for a considerable distance. This is particularly apt to be true in the early spring when warm weather sets in quite suddenly before the winter accumulations of sludge are taken care of. The depth to which the sludge is applied to the beds varies in different places. At Marlboro it is about 0.5 to 4.0 inches. During winter the depth becomes greater at most places. The drying period varies widely. The material as removed is ordinarily used on neighboring lands for fertilizing purposes, although the proceeds from sales are small or nothing.

At Gloversville Mr. Vrooman states that 2.75 acres of sludge beds are to be used for an average sewage flow of 3 million gallons daily. At North Attleboro, Mr. Barbour provided 0.47 acre for 500,000 gallons daily.

AIR DRYING OF SLUDGE

This arrangement differs but very little from the use of sludge beds, as described above. Its chief distinction relates to the disposal of water by evaporation rather than by filtration. Where the material of the bed is impervious and the sewage is applied to considerable depths, air drying becomes the chief factor rather than filtration. Naturally the rate of evaporation of the water content in the sludge depends upon the rainfall and climatic conditions with respect to freezing. Where it is tried the results are probably less satisfactory than would be the case if porous underdrained sludge beds were in use. Many months even in warm weather may be required for unsepticized sludge to become spadable.

While the method is cheap it is likely to be objectionable as to flies and odors, as is true of porous sludge beds and the disposal of unsepticized sludge by dumping or filling. Hygienically it is open to criticism similar to that applicable to the use of garbage or refuse for filling unused land. Disease germs may be transmitted by flies or other winged insects. Many and probably most of these bacteria quickly die in sludge, but there is uncertainty as to the fate of the resistant minority. This statement does not apply to septicized sludge.

Aid has been sought in the use of quick lime and of hypochlorite of lime, but without much success. Except for very small projects there is difficulty in applying these chemicals with sufficient uniformity over the surface. Their application in sufficient quantities to the sludge, as it is delivered to the beds, in order to aid as deodorants has seldom been tried apparently for large projects.

At Frankfort and some other places in Germany use has been made of "facilol," a tar product of a specific gravity of 0.79. It is a thin brownish oil which is sprayed over the wet sludge as soon as removed. According to the statements of Messrs. Schmeitzner and Elsner, it is effective in preventing troubles from odors and insects. Decomposition of the sludge seems to be prevented by the germicidal effect of the phenol substances comprising about 28 per cent. of the oil. It is further stated that it prevents insects from securing food and thus they as well as their eggs and larvæ are killed. Further, the film formed by the oil when placed over the sludge is so coherent that it closes immediately

if broken by gas bubbles or currents. This is the way that it prevents the escape of odors.

The cost of this oil is given as $2.15 per hundred pounds, or about 13.5 cents per gallon. At Frankfort one gallon is applied to from 5 to 9 square yards.

DISPERSION IN WATER

This method is used at London, Glasgow, Manchester, Salford, Boston and Providence for disposing of the sludge resulting from various forms of sedimentation treatments. It allows an economical inoffensive disposal to be obtained, having considerable merit for seaboard towns or those upon certain large rivers or lakes.

In the report of April 25, 1911, by the Milwaukee Sewerage Commission it was recommended as a temporary measure that the sludge be dumped in Lake Michigan about 15 miles from shore. This plan is not spoken of favorably in Mr. Wisner's Chicago report. Attention is called to the uncertainty of having the discharges dumped in the proper spots, and the difficulty of so doing in rough weather.

For inland cities, however, few are upon rivers large enough to allow this method to be considered seriously. Considerable study at Columbus was given to this as a means for the disposal of sediment at times of flood flow in the Scioto river. In Mr. Johnson's Columbus report, pages 132 and 327, it is indicated that when there is a dilution of about 1 in 800 no objectionable results are likely to occur as to putrescibility or decomposition odors. The method seems unattractive at first glance from a hygienic standpoint, but it is not likely that there are a great many living disease germs in the sewage sludge. Moreover, storm overflows convey enough fresh sewage into the river to obscure in all probability the sanitary aspects of this method of sludge disposal.

At Columbus it was the original intention to provide an optional arrangement for the disposal of sludge on land in the event that adequate flows in the Scioto river did not appear with sufficient frequency to allow of the practice of sludge dilution. When the large Columbus works went into service shortly after the completion of the Columbus storage dam, difficulties were encountered during the second summer of operation in disposing

of the sludge in this manner. The alternate arrangements had not been completed as originally planned, but were added during 1911.

In the Third Annual Report of the Division of Sewage Disposal of Columbus, 1910, Mr. Hoover speaks of the dilution method as adequate at times of heavy floods. The mixing is not complete until the sludge has flowed about one mile. There is enough oxygen in the flood water to prevent offensive decomposition. The fate of stranded solids if any is not discussed.

LAGOONING

This is the next step in America in the efforts to dispose of sludge at an economical cost and moderate freedom from odors, although earlier trials in Europe were not ordinarily successful. At Reading it has been practised for some four years. It was prompted by efforts of the city to circumvent the Cameron patents through cleaning out the sludge at intervals of six weeks. It practically amounted to efforts to digest the sludge or septicize it outside of the sedimentation tank. Experiences with it are described by Mr. Chase in the *Engineering Record* of Aug. 13, 1910. On adjoining low land near the Schuylkill river dikes were built about 5 feet high. The sludge from the preliminary sedimentation tank is removed by gravity to the lagoons so formed. During the first two years of operation about 5000 cubic yards of wet sludge were disposed of on this area. Over the surface a scum forms beneath which the sludge appears to become quite completely liquefied. No odors are noticeable 200 feet from the lagoons and the method may be stated to be successful so far as offensive smells are concerned. The conditions at Reading are quite favorable to the use of this method, but even there it has its limitations as it will soon be necessary to dispose of the accumulated residual material or to resort to some other method of sludge disposal.

At the Philadelphia testing station experiments with the lagooning of sewage were tried. The results are of more interest as an air-drying study than as to the digestion or liquefaction of accumulated solids. In fact, the digestion of solid matter does not seem to have been a special object of investigation.

This question is allied to the digestion of sludge in separate tanks and will be taken up again in connection with septicization.

But here it may be mentioned that experiences similar to those at Reading have been studied at the Chicago sewage testing station in tanks of artificial construction. The chief difficulty according to Mr. Langdon Pearse has been that such a large proportion of the suspended matters were lifted to the surface, where they for ned a hard cake (see Fig. 32). In fact, it became necessary to remove most of the solid matters at the surface with a fork. The longer-continued experience at Reading is probably

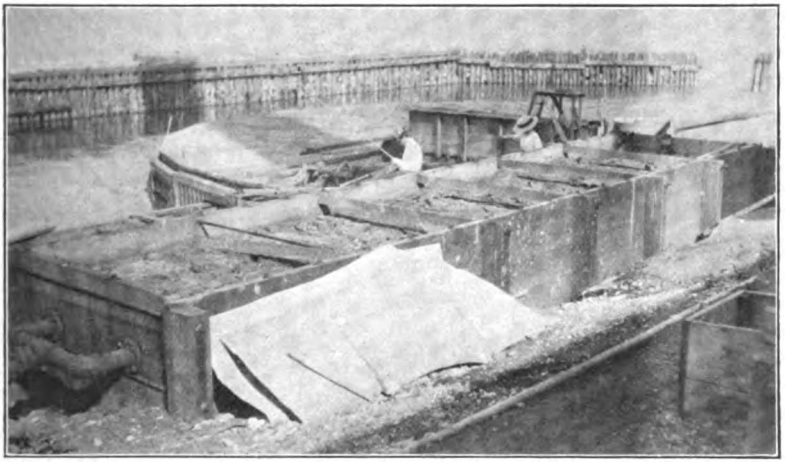


FIG. 32.—Sludge digestion tank, Chicago, Ill.

not at variance in indicating that style of action, but the time interval was probably sufficient to see substantial digestion of the solids through actions going on in the lower layers of this so-called "scum" and beneath the flow line. Perhaps another factor of importance at Reading was the application of fresh quantities of sludge about once in six weeks, thus breaking up the surface mat and reestablishing septic action along more effective lines.

In *Engineering News* of Jan. 25, 1912, Mr. Saville speaks of experiences at Elberfeld, Germany, where the results were unsatisfactory in his opinion as to odor and high cost of maintenance. The area for sludge disposal was 2 square feet per inhabitant.

The greater depth causes a smaller area of surface to be exposed than with sludge beds or with air-drying methods.

This tends to lessen odors, but the process is subject to objections as to flies and odors, as already described. Why it is that no trouble has been experienced at Reading is not known.

FILLING OR DUMPING

This method is in quite general use for the deposits removed from catch basins. At Toronto it is proposed to use the sludge for filling in low waste land near the lake shore. With it will be mixed some street sweepings and other dry wastes. It is proposed to remove sludge from the tank daily and pump it to the marsh. Messrs. Watson and Hering in 1909 stated that "we are of the opinion that if ordinary care is exercised no offensive odor will be perceptible more than a short distance from the site of the depositions."

DIGESTION TANKS

This question has been touched upon already in connection with the lagooning experiences at Chicago where a distinct nuisance was observed. It deals particularly with septicization details, as mentioned in Chapter XIV. Here it is spoken of as the means adopted for treating the sludge removed from the plain sedimentation tanks at the large works at Baltimore.

For more than a year such a plant has been in service in Forest Park, one of the suburbs of Baltimore. Noticeable odor is stated by Prof. Bass (*Journal of the Association of Engineering Societies*, Vol. XLVII, page 58) to have been observed several hundred feet away on some occasions after sludge has been applied to the tank. Mr. Hendrick, Chief Engineer of the Baltimore Sewerage Commission, speaks of the plant as generally successful. Further experience at Baltimore will be looked for with great interest.

TRENCHING

In a number of places abroad and in some instances in this country on a small scale sludge has been applied to land in trenches or deep furrows. After the application of sewage to the trenches and some of the water has disappeared, these trenches are covered with earth, thus providing a burial of the sludge. When carefully applied, this method minimizes odors. But it requires considerable area, as the land becomes less and less

porous with subsequent applications. For large works the expense becomes burdensome. This is the reason of its abandonment at Birmingham, England. It is not capable of easy or regular use during severe winter weather.

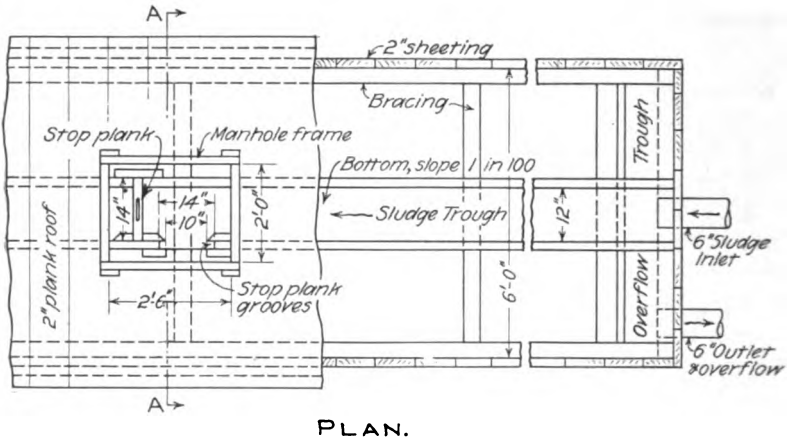
COVERED SLUDGE TRENCHES

The author has had some experience at Kings Park, Long Island, with the treatment of sludge from plain sedimentation tanks of the Dortmund type. At frequent intervals the sludge is removed from the bottom of these tanks by opening a gate on the outlet pipe through which the fresh sludge by the weight of the superincumbent sewage is delivered to covered sludge trenches. These sludge trenches (Fig. 33), two in number, are each 100 feet long, 8 feet deep and 6 feet wide, braced on the sides and top with rough 2-inch lumber and covered with a foot or more of sandy soil. The sludge is distributed lengthwise in these trenches by means of a trough so that it can be deposited at different points by adjustments made through openings which are ordinarily covered. No trouble has been experienced with odor from these trenches.

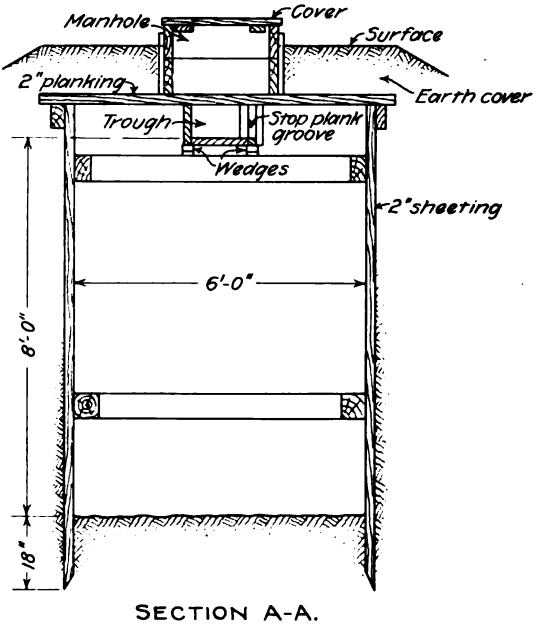
This plant after a year of service was carefully examined and found to contain about 2.0 cubic yards of spadable sludge per million gallons of sewage, equal to about 5.4 cubic feet per thousand population daily. This is equivalent to about 64 tons of wet sludge per thousand population annually. The average water content was not determined but was probably between 60 and 70 per cent. Owing to the sandy material the free water seems to disappear quite promptly and septicization had occurred to but a slight extent. The sludge had the appearance of fresh air-dried sludge.

What the reasons are for the lack of effective septicization is not known. If the water content had not been removed so quickly, as would be the case with trenches in fairly impervious material, the results might have been different. It may be that it is only a question of lack of proper bacterial seeding, or it may be that the result was controlled by factors related to bacterial antagonism.

From the standpoint of disposing of sludge in an inoffensive way, the method seems to have considerable merit for some small installations. The disposal of the sludge is not complete



PLAN.



SECTION A-A.

FIG. 33.—Plan and section of sludge trench, Kings Park, L. I.

in the form in which it is deposited in these trenches unless additional ones are built from time to time so that the sludge permanently remains in them. That involves the question of economy of numerous trenches, as compared with methods for the removal from trenches of limited size of the sludge in night-soil carts and application to land with subsequent covering with a plow. Until such figures are available for a given site it is scarcely feasible to compare its cost with that of other non-odorous means of sludge disposal. In March, 1912, when it was decided to enlarge this entire plant to provide for an increase of 50 per cent. of population, it was determined to convert the settling tanks to the two-story type and septicize the sludge in the lower compartments.

INCINERATION

If sludge can be sufficiently freed of its water, it is possible to dispose of it in conjunction with other city refuse in modern incinerators or destructors. American experiences are practically nil in this regard. A dozen years or more ago Mr. Eddy at Worcester, attempted to burn sludge after more or less air drying. The method was not adopted there.

At Coney Island, New York, chemically precipitated sludge was burned years ago in a crematory after mixing with sawdust. It was discontinued after a short time.

Mr. Allen's book on sewage sludge records the Frankfort experience of incinerating sludge of 75 per cent. water after mixing it with three parts of city refuse. In England pressed sludge cakes are incinerated after mixture with two parts of refuse. At Elberfeld it is stated that sludge of 60 per cent. water can be burned without adding coal by using a forced draft.

When coal or peat is mixed with sludge it can be burned under boilers, provided the sludge contains somewhat less than 80 per cent. of water. The loss of heat in evaporating water makes wetter sludge impracticable for burning. The burning of sludge with coal was studied at Philadelphia in 1910 on a small scale.

DESTRUCTIVE DISTILLATION

There are no practical experiences with this treatment in this country. At Lawrence, Messrs. Clark and Gage reported experiences on an experimental basis in the 1908 report, page 496, of the Massachusetts State Board of Health.

The cost of the process and the value of the coke and gases produced are not definitely known. The cubic feet of gas produced per ton of dry solids were as follows: settled sludge, 6600; chemically precipitated sludge, 8100; septic sludge, 4900. The coke amounted to 45 to 65 per cent. of the weight of the dry sludge. While it was soft and friable it is stated that it could be burned on properly constructed grates, with the heat used either for steam raising or for drying wet sludge. The coke also contained from 1.1 to 1.7 per cent. of P_2O_5.

MECHANICAL DRYING

Some study has been given by American engineers to the drying of sludge in centrifugal machines. So far as known, no

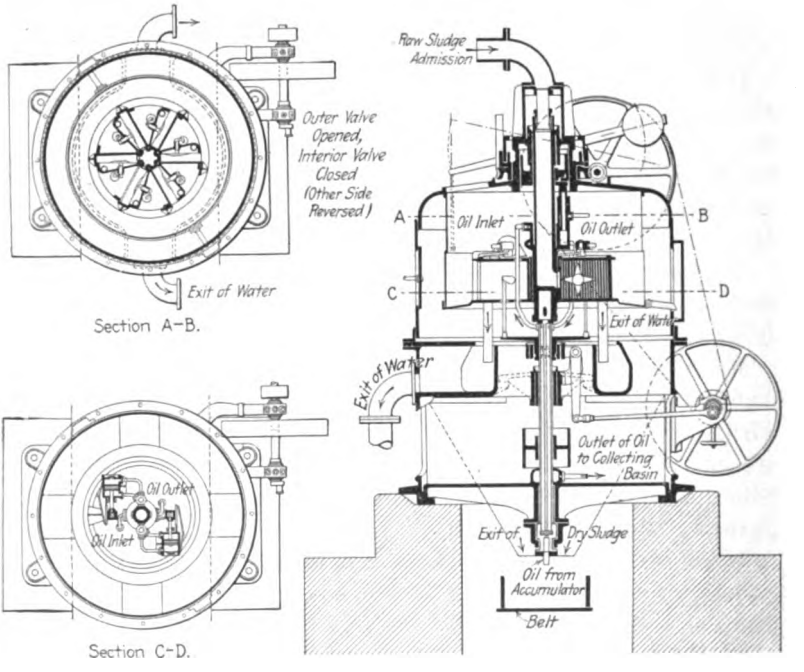


FIG. 34.—Schaefer-ter Meer centrifugal sludge drying machine.

practical data of value are available except from Europe. In the *Engineering Record* of Oct. 17, 1908, there is a description of the Schaefer-ter Meer centrifugal machine, of which six have been installed at Frankfort, four at Hanover and two at Harburg.

Fig. 34 shows sections of the main features of the machine.

The wet sludge enters the center of the revolving chamber or drum through an overhead inlet pipe while the machine is in motion. In this chamber are six radial compartments on one side of which is a radial strainer plate. The slots are about 0.4 by 0.02 inch. Slide valves controlled by oil under pressure close the compartments on the inside and outside.

The heavier particles of the sludge are thrown by centrifugal force against the outer part of the compartments and the water, which is lighter, moves inward. The water runs through strainers and flows through an annular waterway to the outlet pipe. As the water escapes fresh sludge takes its place.

The process is a continous one, with the compartments becoming finally filled with a dried mass. Then the inner valves are closed and after a number of revolutions of the drum the outer ones are opened, whereby the dried material is thrown outward against the casing of the machine. In so doing the sludge is broken into small pieces. It falls through a funnel on to a belt conveyor below. A scraper is moved backward and forward by a special mechanism so as to keep the strainer area free. Operations are all automatic. The drum makes 750 revolutions per minute and the required power is 12 horse-power. Depending on the quality of the undried sludge, the drying period ranges from 1.5 to 5 minutes. About 2.5 to 5 cubic yards of untreated sludge can be dried per hour. The finished product is crumbly, with a water content ranging from 55 to 70 and averaging about 60 per cent. It weighs about 1520 pounds per cubic yard, according to German data, but varies with the percentage of voids. The volume is reduced to about one-eighth of the untreated sludge. The water from the machine is highly putrescible.

German data indicate that these machines cost about $5500 each and that the cost of operation ranges from $0.35 to $0.50 per ton of dried product, depending upon the size and output of the installation. These machines are preferred in Germany to sludge pressing. The relative cost of these two methods is not definitely known for given conditions, as it depends much on the lime to be added to the presses.

Drying machines are of aid in sludge treatment through the preparation which they afford either for incinerating the sludge or using it directly as a fertilizer or as a filler for fertilizers.

Use for Fertilizers.—An article in the *Engineering Record* of Jan. 21, 1911, contains many interesting comments by Mr. W. B.

Ruggles. Reference in particular is made to a rotary drier of American make which was recently installed at Bradford, England. This article does not go into much detail as to the type of drier, with which the sludge is heated for about 20 minutes to a temperature slightly above the boiling point. The dried product is of 8 to 10 per cent. water content, and about the size of peas. It is inoffensive and can be readily ground to a powder, making an ideal filler for fertilizers on account of its physical and chemical properties.

Remarkable comments are given as to the theoretical manurial value of the sludge. He speaks of the Chicago drainage canal as the throwing away of fertilizing material worth more than $2000 per day, which, if it had been originally planned for, could have been recovered for an expenditure of less than half that amount. Similarly he speaks of New York emptying into the rivers and the sea material which is worth at least $1,500,000 per year. The writer states, however, that it is doubtful whether it is now possible to recover these elements with the existing arrangements of the sewerage system for what the product would bring in the market.

Mr. Ruggles bases his proposition commercially upon figures as follows:

Cost of filter pressing per ton	$1.00
Cost of drying per ton	.35
Cost of grinding per ton	.16
Cost of bagging per ton	.15
Total	$1.66

He states that with a value of $4. per ton, which is less than one-half the value as given by the "American Fertilizer," there would be a profit of $2.34 per ton. In addition to this, it is stated that there is the saving of not having to dispose of the sludge in other ways, amounting to about 60 cents per ton.

This question is a complicated one as to arriving at sound conclusions from representative data, particularly with a product that varies so tremendously in its composition as to water, inert mineral matters, and substances of fertilizing value. European data are on the whole not promising as to commercial success. The outlook for practical success in America is no more hopeful.

SLUDGE FROM FINAL SETTLING BASINS

Coarse-grained filters unload suspended matters from time to time so that in most of the later projects basins are provided in

which to settle these coarse matters. Data are most definite at Reading, where one such basin has been in service since January, 1908. With this unusually well-screened and settled sewage there is obtained after its filtration a deposit in the final basin of about 2 cubic yards of sludge per million gallons of effluent. It was removed seven times during the year 1910. It is pumped to adjoining land, where it dries quite quickly to an inodorous product resembling humus.

Flat-bottomed tanks should have a slope of about 1 to 50. Mr. Chase favors a weir near midlength of the tanks, so as to aid in the removal of particles that move on account of entrained gas. Notwithstanding the high oxygen content of the effluent, the sludge on the floor of the tank decomposes with much gas. The purpose of the weir with a fall of perhaps 6 inches would be, according to Mr. Chase, to break up the sludge and to dislodge the gas that causes the particles to float.

Hopper-bottomed tanks have been designed for several projects on the basis that they facilitate the frequent removal of the sludge. Two-story tanks of the Imhoff type have been recommended by the author for some small plants.

The flat-bottomed tanks are cheapest, but they are not always best for this service.

RÉSUMÉ

Grit chambers are inadvisable in connection with sewers receiving sanitary wastes only. For the flow of combined sewers they are distinctly helpful in connection not only with purification works but also inverted siphons, screening chambers and pump pits. The velocity of flow should not be reduced much if any below 1 foot per second. Multiple compartments should be provided to take care of varying volumes of flow. The quantity of grit varies widely, depending upon the quantity and quality of street wash and trade wastes. Ordinarily the quantity comes within a range of about 4 to 12 cubic feet per million gallons. The material should be substantially free of putrefying matters and may be disposed of on vacant land.

While sedimentation in one form or another is embodied in all recent projects of magnitude and is a feature of about 80 per cent. of all municipal plants now in service, there are only about 20 per cent. which embody plain sedimentation as distinguished from septicization. Many of these tanks were designed during an

intermediate period following uncertainties as to single-story septic tanks and before two-story septic tanks had their present rating.

The usefulness of sedimentation has been found chiefly as an aid to filtration. Such basins are also serviceable in the clarification of the effluent of coarse-grained filters, as discussed beyond, and in preventing objectionable sludge deposits when sewage is disposed of by dilution, as explained in Chapters VIII–X. The latter field will expand rapidly as to stranded solids which decompose between floods either on or near the shore and as to sludge banks in deep water that is now unduly deoxygenated.

Sedimentation basins are capable of removing from 50 to 70 and ordinarily from 60 to 65 per cent. of the total suspended matters in sewage. The removal of total organic matter is about half this amount. Of the readily deoxygenating constituents in sewage the removal is rather less than the total organic matter, perhaps 80 per cent. according to present evidence. In time, however, the sludge will deoxygenate overlying water in streams, lakes and oceans. The bacteria in the entering sewage are removed to approximately the same extent as the total suspended matter, although this removal is frequently obscured by the growths of harmless types of bacteria. The removal of fats seems to vary from about 30 to 50 per cent. Floating matters may be removed in these tanks or basins.

The capacity of settling tanks is ordinarily taken now at from 2.5 to 4 hours' average flow. The velocity should be kept preferably within a range of from 0.166 to 0.50 inch per second.

The depth of basin is theoretically of little or no aid to sedimentation. Yet practically the cost of construction of shallow basins and the expense of cleaning them at very frequent intervals, as well as the small portion of suspended matter directly influenced by theoretical considerations, have resulted in the present practice of adjusting the depth to features of advantageous construction regardless of its influence on sedimentation. It is true with sewage as with muddy waters that there is a substantially equal mixing of the suspended matter particles in sewage from the surface to just above the sludge deposits on the bottom of the basin. This mixing is due in part to convection currents and in part to vortexual motions resulting from entering velocities and wind action.

Baffles should be provided to prevent dead spaces and cause

as nearly uniform a rate of flow as practicable throughout all portions of the basins. Care should be taken not to establish detrimental currents as a result of baffling, nor to arrange the baffles so as to retard needlessly the convenient removal of sludge.

Inlet and outlet connections should be arranged to promote uniformity in the rate of flow throughout the basin and its several compartments. The inlet connections should be free of corners and of a cross-section to prevent the deposit of putrefying solids. The outlet should be arranged in case of flat bottom tanks to assist the removal of clarified sewage preparatory to cleaning. Movable weirs are probably the most convenient and economical arrangement.

Slopes to flat bottomed tanks should be at last 1 to 50 and drains should be materially steeper in their slopes than if they were to receive corresponding volumes of water or sewage. The slopes should increase with decreasing water content in the sludge.

Hopper-bottomed tanks of several types have recently been designed for the removal of sludge without the emptying of the tank. They have a distinct field of usefulness, although their construction in connection with upward flow tanks may be prohibitive as to expense under certain circumstances.

Sludge removal is one of the most difficult features in connection with sewage disposal. In quantity it ranges from about 5 to 50 cubic feet per thousand population daily, depending much upon the water content of the sludge. The putrescible character of the sludge combined with its bulk on account of the water which it contains are two troublesome elements in the sludge.

So far as now known there is little or no hope of obtaining commercial success in the utilization of ordinary sludge as regards its fertilizing qualities or the extraction of its grease.

The dispersion of sludge in deep water is perhaps the cheapest and best way of disposal under some circumstances. Application to land, preferably to drained sludge beds, is suitable for small plants, although more care should be devoted than has been the case ordinarily up to this time. Odors and flies are bothersome, but they may be controlled by the application of suitable oils.

Lagooning, trenching, sludge pressing and mechanical drying all have their fields of usefulness, but the present tendency now is to consider these much less favorably than the septicization of the sludge in two-story tanks, as discussed in Chapter XIV, followed by quick-drying on specially prepared beds.

CHAPTER XIV

SEPTICIZATION IN CONNECTION WITH SEDIMENTATION

Septicization is the term applied to the anaerobic decomposition of sewage whereby intensive growths of bacteria directly, or more probably indirectly through enzymes, bring about the liquefaction or gasification of solid organic matters. It means the rotting of these solids until when carried to its full final limits the organic matter is so thoroughly rotted that it may be said to be humified. Besides the fairly stable residual substances there are formed numerous decomposition products of varying character and stability. Frequently the process is spoken of as putrefaction, but this is not technically precise according to strict modern nomenclature, as explained in Chapter II.

Two Phases of Process.—The septic process has been generally taken to mean a combination of sedimentation and anaerobic decomposition. There are two distinct phases to the process. One refers to the clarification of the sewage with a view to an improvement in its composition as compared with untreated sewage, either for direct discharge into a watercourse or as a preparation for filtration. The other relates to the treatment or digestion of the sludge or deposited solid matters to facilitate their disposal.

Lack of care in differentiating between these two aspects of the process has led to more or less confusion and delay in giving the subject a correct standing. As an aid to filtration the benefits of clarification have been frequently confused with claims for improvements due to bacterial action upon the organic contents of the flowing liquid or septic effluent. This was well cleared up in 1905 by Mr. Johnson in his Columbus report. On pages 265 and 315 he showed that for coarse-grained filters of the contact or sprinkling type the septic process, as compared with plain sedimentation in tanks of corresponding size, produced no beneficial effect that could be readily measured.

Clogging Aspects.—For sand filters the septic effluent was less desirable at Columbus (page 190 of report) because of clog-

ging due to suspended matters being carried from the septic tank at irregular intervals on to the sand bed. Gas-lifted particles of the sludge in the septic effluent doubtless produced more or less clogging of the sprinkling filter nozzles, but the effect of this was not fully realized at Columbus until after the large plant went into operation. Scum was rarely a factor at the Columbus testing station. Some of these features were noted by Messrs. Eddy and Fales at Worcester, as stated in their paper of 1906.

In the early days of the septic tank it was used so generally with contact filters, in which clogging is less quickly noted than with sand filters or sprinkling filters, that some time elapsed before the effect of abnormal quantities of solid matters in the effluent was fully appreciated. As stated on pages 118 and 131 of the Columbus report, it was recognized that gas-lifted particles should be deposited and not appear in the septic effluent, but the means adopted there at the large works were not adequate.

Effect upon Organic Matter.—It is undoubtedly true that some of the decomposition products in stale or septic sewage are more easily oxidized or nitrified than are the same organic atoms as combined in the more complex molecules found in fresh sewage. This is particularly true as regards direct oxidation. It is demonstrated by laboratory tests and by the quickness with which aerated septic effluents absorb a portion of the oxygen obtained from the atmosphere in the course of aeration. Mr. Clark describes instances where the oxygen in septic effluents, after mixing with oxygenated water, was largely and even wholly exhausted before the samples could be analyzed. This period was three or four minutes. (See Massachusetts State Board of Health Report for 1900, pages 387–92; also Report of 1908, page 480.) This was also recorded by Mr. Barbour in his paper in 1905 before the Boston Society of Civil Engineers in describing the Saratoga plant, as stated in the *Journal of the Association of Engineering Societies*, Vol. XXXIV, page 48. As the septic effluent entered the aerator it contained no dissolved oxygen. Immediately after it left the aerator it showed 70.4 per cent. of the atmospheric oxygen necessary for saturation at the given temperature. After the effluent left the aerator and flowed to the sand filters, Mr. Barbour reports that the percentage of dissolved oxygen in this short interval of time was reduced from 70.4 to 40.4 per cent. of saturation.

Relation to Nitrification.—Nitrification in a measure also behaves differently, according to the extent to which septicization or staling of the sewage has taken place. This was noted by the author at Lawrence in 1894, as will be seen from the results given on page 478 of the Report of the Massachusetts State Board of Health for that year. In warm weather there was not much difference in the period required for establishing nitrification in sand filters receiving fresh sewage and stale sewage. In cold weather, however, in the filter receiving fresh sewage nitrification took place much more slowly. On the other hand, highly septicized sewages, especially if applied to contact filters, may be nitrified only with difficulty, as mentioned by Mr. Clark in the references above given.

Oversepticization.—In filtration processes in general it is apparently something of a handicap for the influent to possess the results of bacterial activities along anaerobic lines, because it is necessary for the filter to maintain these functions on an aerobic basis, thus calling for more or less of a reestablishment of the mode of bacterial life. Futhermore, some decomposition products are of a toxic nature with respect to the bacteria that it is desired to cultivate. Hence, there is no question about septic action being capable, if carried too far, of doing more harm than good.

The formation of toxins by oversepticization should be guarded against in designing a plant so far as practicable.

Sludge Digestion.—Of genuine merit is the septicization or humification of sludge whereby it is converted into a non-odorous stable substance which ordinarily can be disposed of more cheaply and satisfactorily than in any other form. This step has been taken in various ways, some causing trouble from odors and others not. The real problem now is how to build and operate works which in practice will insure the advantages but not the disadvantages of anaerobic decomposition of sludge, and at the same time give to the treated sewage the full benefits of clarification at all times without any of the prejudicial influences which may attend the septicization of the effluent.

HISTORY AND USES

Septicization within the modern sense of the term dates from about 1896, when the so-called septic tank was developed by Mr. Cameron and his associates at Exeter, England. This

plant is well outlined by Mr. M. N. Baker in his book on "British Sewage Works," pages 23–8.

Prior to that date the anaerobic decomposition of sewage of course took place in an incidental unscientific fashion to a greater or less extent in many cesspools. The history of the antecedents of the septic tank is outlined in a paper by Mr. Leonard Metcalf read in 1901, before the American Society of Civil Engineers (see *Transactions*, Vol. XLVI, page 456). This question has promoted a great deal of discussion and some bitterness of feeling as to what extent, if any, patented devices and processes should receive recognition from the engineering profession. More will be said of the patent question later. Here it is sufficient to state that the matter became involved in litigation through the efforts of the owners of the Cameron patent in the United States to collect royalties from the village of Saratoga Springs, New York.

In the early days of the septic tank, claims which are now known to be grossly extravagant were made for this process. It was even claimed by some that all deposit from the flow of combined sewers would be destroyed, although a little thought will show that this is impossible on account of the suspended mineral matter entering the tank. In England the developments at Exeter attracted great attention and were confirmed at Leeds and Manchester. Many chemical precipitation tanks were used with but slight changes as single-story septic tanks.

In America this process was received with considerable favor and was installed by quite a number of institutions, towns, and small cities. In 1904 the author found that there were some 29 installations of septic tanks in towns of over 3000 population, serving an aggregate population of about 160,000. Then followed the Columbus investigations. In 1906 a review of various American and European experiences was made in the interests of the city of Baltimore. At that time the single-story septic tank was at the height of its reputation, and installations were being made quite rapidly.

Next came the decisions in the litigation over the Cameron patent on tanks as applied at Saratoga. In 1907 a decision was rendered by the United States Circuit Court for the Northern District of New York, declaring invalid both the apparatus and process claims of the Cameron patent. It was taken on appeal to the United States Court of Appeals, Second Circuit, and early in

1908 a decision was rendered affirming the opinion of the lower court as to the invalidity of the apparatus claims but reversing the decision on, and declaring valid, the process claims. This condition of affairs aroused much interest on the part of engineers. One or more associations of interested cities was formed for the defense of such suits. An effort was made to have the United States Supreme Court pass upon the matter on an application for a writ of certiorari. This application was denied. A period of circumvention followed, during which many tanks previously operated as septic tanks were cleaned out from time to time. From the record in the Saratoga case some understood that if the sediment is removed at intervals of six weeks or less the tanks technically become not septic tanks, but plain sedimentation tanks. But the Cameron Company states that this viewpoint is not of general application.

As to new plants following the Saratoga litigation, there was a period when plain sedimentation was in vogue for the large projects with the sludge treated in a variety of ways. In some of the large plants efforts have been made to digest or septicize the sludge in various arrangements of lagoons, trenches, or masonry tanks.

More recently there have come to the attention of engineers the two-story tanks of the Imhoff type, in which clarification takes place in the upper compartment and septicization of the sludge in the lower. As the situation now stands, it is the latter style of tank that is receiving the most attention from those considering large sewage disposal projects. Notwithstanding this, there are many small installations of single-story septic tanks apparently giving satisfaction at present. As views as to the use of septicization are not now well crystallized, an effort will be made here to review the question with considerable fullness.

In 1911 Mr. Kenneth Allen states that there were then about 200 septic tanks in use in the United States.

EFFICIENCY AND UTILITY

The clearest conception that can be given of septicization is that this process, when applied at its best, gives the removal of constituents of sewage as described on page 422, in the preceding chapter on "Plain Sedimentation"; and that the resultant sludge is put in shape to be disposed of more inexpensively and

with less likelihood of offensive smells than is generally the case by other methods. To some extent aid is received from the mixing which the sewage receives within the tank.

Table 66 shows some annual average results of suspended matter and oxygen consumed in the sewage before and after treatment in some well-known tanks. Septicization was a well-marked feature of the tanks at Plainfield and Columbus, while the Reading tank was cleaned at such frequent intervals that it was more of a plain settling tank than a septic tank. As shown in the footnote, there were differences in the methods of analyses, so that the results are not directly comparable with each other.

The average periods of flow through these tanks without making allowance for sludge accumulations were approximately 9, 7 to 10 and 12 hours, respectively.

At times gas-lifted particles appeared in the effluent and gave results much different from these averages. This will be discussed later.

TABLE 66.—ANNUAL AVERAGES OF SUSPENDED MATTER AND OXYGEN CONSUMED IN SEWAGE BEFORE AND AFTER PASSAGE THROUGH VARIOUS SEPTIC TANKS

Tanks	Year	Suspended matter			Oxygen consumed		
		Parts per million		Per cent. removed	Parts per million		Per cent. removed
		Influent	Effluent		Influent	Effluent	
Plainfield	1909	134	52	61	74	50	32
Plainfield	1910	152	56	63	76	52	32
Plainfield	1911	173	64	63	83	57	31
Columbus	1909	201	82	59	61	38	38
Columbus	1910	211	80	62	51 102[1]	34 73[1]	33 28[1]
Columbus	1911	287	99	65	48 131[1]	31 95[1]	35 27[1]
Reading	1908	.....	.....	.....	58	26	55
Reading	1909	157[2]	64[2]	59[2]	56	28	50
Reading	1910	169[2]	88[2]	48[2]	51	30	41
Reading	1911	151[2]	102[2]	32[2]	38	28	26

[1] Special test based on withdrawal of dissolved oxygen from water, as stated by Mr. Hoover in *Engineering News* of Mar. 16, 1911, page 311.

[2] Turbidity, not suspended matter.

Efficiency of Process.—Extravagant claims in earlier years have handicapped the process somewhat, so that there is a wide difference in viewpoint now to be noted. Some people claim and endeavor to put in practice the thought that this is a complete method of sewage purification. Others not only take the opposite view but think that as an aid to filtration there is serious room for doubt as to its applicability.

Personally the author is not in favor of septic tanks as the only mode of sewage treatment unless the effluent may be suitably dispersed in an adequate volume of water so as not to produce a nuisance. This does not prove to be the case frequently in those districts where the method has the reputation of being a complete process. In a number of places in the West the author has seen septic tanks with the effluent flowing along a "dry run" until it reaches a stream in which the flow is extremely small. In small installations where the raw sewage is fairly fresh there are undoubtedly times when the septic effluent is fairly clear. There are other times and conditions when the septic effluent has not lost its dissolved oxygen and would not be called in the ordinary sense either stale sewage or septic sewage. It is practically fresh settled sewage. These are the conditions that have brought warm advocates to the septic tank as a complete method of sewage disposal. If the effluent can reach promptly an adequate body of diluting water it is probable that no offense as to smell or sludge deposits will ordinarily result. On the other hand, it is not to be forgotten that now and then such septic tanks, without apparent warning, will disgorge and unload a considerable volume of suspended matter that has remained for a varying period of time in the tank and has undergone septicization and decomposition to some extent. Larger and better baffled tanks than hitherto used would probably reduce this disgorging.

Where a sewage is old, as found in the outfall of fairly large sewerage systems, the clarification is less complete in the ordinary septic tank than when used on small systems, and the effluent is normally dark-colored and somewhat foul-smelling before it starts on its way to a suitable watercourse. Under these circumstances there is not the opportunity to commend this arrangement that obtains with some small installations as above-mentioned.

Bacterial Removal.—Bacterial removal, and especially the

removal of disease-producing germs, is a question upon which data are not as well defined as desired. At its best the septic tank shows a removal of the total bacteria of the influent roughly corresponding to the percentage reduction in the total suspended matter. There are numerous exceptions to this rule. One of them is found at times when tanks are disgorging and more or less sludge, representing perhaps accumulations of months, is belched forth into the effluent. Another exception results from bacterial growths within the tank. These are associated with complex conditions of symbiosis and antagonism. Some bacteria may be killed off almost entirely as a result of toxic products, while these products may actually promote directly or indirectly the growth of other forms of bacteria. The very process of septicization, involving bacterial decomposition, means intensive growths, and whether or not the effluent will show any result of such growths is difficult if not impossible to forecast uniformly and reliably.

Coming to the more serious question of the fate of disease germs, the evidence is meager. So far as known disease germs do not multiply under these conditions, and it is probable that antagonism plays a part normally to reduce the life to less than what it would be in ordinary waters. Some of the resistant minority of such germs as those of typhoid fever and Asiatic cholera will probably live for quite a time within septic tanks, particularly those which are encased in suspended particles. Such germs may, of course, appear in the effluent of a septic tank a long time after they enter the inlet.

Another phase of this question relates to disease germs which may be found in solid particles which are disgorged from septic tanks at times and become stranded along the watercourse into which the effluent discharges. Knowledge of the transmission of these germs by flies renders possible a hygienic objection which was not considered in the early days of the septic tank.

Summary.—Speaking generally of the efficiency of the septic tank, we may say that from the hygienic standpoint such an effluent should not be discharged into a body of water intimately associated with unfiltered drinking water supplies or with shellfish layings, unless it receives some form of treatment to destroy objectionable bacteria. Fortunately, we now have available an economical process which is efficient when carefully applied.

Reference is made to the hypochlorite treatment, as will be described in a subsequent chapter.

As an aid to the dilution method where the raw sewage would cause objectionable sludge banks in the body of diluting water, the process is satisfactory only when the sludge and scum are retained within the tank and not discharged at intervals in large quantities with the effluent.

As a preparation for coarse-grained contact filters it is of much assistance. But if the filters of this type are of fine material and operated at a fairly high rate the disgorged solids will ultimately cause serious clogging if allowed to reach the filters.

Sand filters are liable to surface clogging if sludge and scum are not prevented from reaching the filters. The influence of this factor varies widely with rates of filtration and other local conditions.

Sprinkling filters may be classed similarly to the contact filters, except that nozzle clogging is likely to be a disturbing element unless the septic effluent is freed of suspended solids by screens, roughing filters or other devices.

In brief, the utility of the septic process is related very closely to the success with which the sludge and scum are prevented from appearing in the effluent or are economically removed therefrom.

TYPES OF TANKS

It is believed that this question of septicization can be explained most satisfactorily by describing its application to different types of tanks. The principal styles of tanks in which this process has been used are as follows:

A. Single-story septic tanks, so-called, in which the sludge and the scum are allowed to remain in the same compartment in which sedimentation takes place.

B. Separate tanks or compartments entirely independent of the sedimentation basin and provided for the specific purpose of digestion or rotting of the sludge after its removal.

C. Travis or Hampton tanks, the first of the well-known two-story tanks in which clarification of sewage takes place in the upper and septicization of sludge in the lower compartment. More or less sewage has ordinarily been allowed to pass through

the lower compartment with a mixing at the outlet weirs of the effluents of the lower and upper compartments but Dr. Travis states that it is not necessary to allow sewage to flow through the lower compartment of his tank.

D. Two-story tanks of the Imhoff or Emscher type, in which every reasonable effort is made to confine sedimentation to the upper compartment and septicization to the lower, without interchange from the lower to the upper other than the quiescent displacement of liquid by the solids that settle down from the upper into the lower chamber.

E. Modified Dortmund tanks, in which the sludge is allowed to accumulate at the bottom, and in which all the liquid passes through all the sludge, after the fashion studied at the Technology and Chicago testing stations.

We will proceed to discuss the process as related to these several types of tanks as follows:

A. THE SEPTIC PROCESS IN SINGLE-STORY TANKS

Septicization has been applied mostly in ordinary tanks or basins, quite closely resembling the horizontal and continuous flow tanks described in the preceding chapter, except that the tanks are somewhat larger than plain settling tanks. Some are covered and some are not. Within certain limits it is correct to say that the process as practically applied has been the same as for plain sedimentation, except that the tanks have been freed of deposits of solid matter only at infrequent intervals or not at all. There are some cases, however, where the tanks have been designed and operated with the specific view of septicizing as much as possible of the deposited solids. Inlet and outlet connections have ordinarily been made below the flow line.

Probably the most comprehensive description of the single-story tank and what may be expected of it at its best is to be found on pages 33–6 of the Report of the Board of Advisory Engineers to the Sewerage Commission of the City of Baltimore under date of May 31, 1906. This Board was composed of Messrs. Rudolph Hering, F. P. Stearns, and S. M. Gray. The late Prof. L. P. Kinnicutt, Mr. H. W. Clark, of the Lawrence Experiment Station, and the author, assisted in the preparation of various data with which they were familiar both in this country

and abroad. This report, coming shortly after the publication of the results of the Columbus tests, undoubtedly marks a period, as already stated, when this method was at the height of its fame. Since that day it has dropped somewhat in public favor, partly in consequence of developments in the field of patent litigation, partly on account of difficulties in securing in practice as satisfactory results as were believed to be possible from experience on a small scale, and partly from the development of improved arrangements by the use of two-story tanks.

SEPTIC TANKS AS DESCRIBED AT BALTIMORE IN 1906

The first purpose of the septic tanks is to cause a deposition of those matters suspended in the sewage which settle to the bottom of the tank when the liquid is brought to rest or when its velocity of flow is very greatly reduced. Experience shows that with a sewage such as may be expected at Baltimore about two-thirds of the suspended matters may be deposited when the sewage is allowed to flow through suitably arranged tanks for a period of six hours or so. Available evidence indicates that the velocity of flow should be reduced on an average to about four millimeters per second, or ten inches per minute. With basins having a length of flow of about 400 feet the sewage at about such velocities is generally clarified on an average about as much as economy permits for this step in the process. The depth of liquid in the tanks will be 12 feet for the maximum. To facilitate as uniform an hourly rate of flow of the sewage to the sprinkling filters as possible it is assumed that the depth of the sewage may be allowed to fluctuate between 12 and 9 feet. In computing the actual net velocity of flow it is necessary to bear in mind that accumulating deposits on the bottom of the tanks will somewhat reduce the available storage depth. To facilitate operations when the works are first built and the quantity of sewage is quite small, and in order to allow of portions being conveniently cleaned, the tanks should have division walls making five and preferably more compartments.

Along the inlet and outlet ends of these tanks there are conduits with suitable branches and gates connecting with each tank. Transverse walls extending to a height of about 8 feet guard against sludge being moved toward the outlet at times of unusually heavy flows. Floating baffles also guard against scum passing with the sewage into the outlet conduits.

The bottoms of the tanks slope to sumps connecting with convenient drains for cleaning. Water under pressure for flushing is also provided.

So far as we are able to judge, the septic treatment under conditions to be expected at Baltimore will not materially affect the character of

the settled sewage passing from the tanks. In fact, the septic treatment relates essentially to the condition and disposition of the sludge. The sludge may be allowed to accumulate for months or perhaps years. Under these circumstances the bacterial action occurs, and on an average probably more than one-half of the total deposited matter would be converted into a liquid or gaseous form. As the bacteria do not attack the solid mineral matter, it is the solid organic matter which is affected. The latter should be acted upon until it contains no more organic matter which will putrefy either in the septic tank or after its removal. The septic treatment, therefore, reduces materially the volume of sludge, and causes the latter, when the septic tanks are properly operated, to become practically inert mineral and humus matter. Septicization is practised to best advantage when this effect upon the sludge is accomplished, and when the septic effluent shows a minimum effect of this bacterial action. We consider this latter requirement imperative and have so regarded the matter in this report, both as to the construction and operation of septic tanks.

This septic treatment results in the generation of a substantial quantity of gas composed principally of marsh gas. The rate at which the gas is evolved, roughly measures the intensity of the bacterial action, and varies at different seasons of the year, depending largely upon the temperature and somewhat upon the kind of organic matter in the sludge and the bacteria present therein. This process continues during the winter weather, but is far more active during the warm season of the year. The gas thus evolved rises to the surface and at times carries up with it some of the sludge, thus forming a scum on the surface of the liquid in the basins. This scum is generally thicker in warm weather than in cold, and in many places it is almost absent during the colder season of the year.

The septic tanks are not provided with covers, as the latter do not facilitate the process except perhaps in climates far more severe than at Baltimore.

Based upon various experiences at numerous places, we have no reason to expect that objectionable odors would be encountered beyond a short distance from these tanks if the latter are well managed. The odors are carried the greatest distance on almost calm, muggy days in summer when there is no strong wind to disperse them. Under these conditions it is safe, in our judgment, to estimate that objectionable odors will not be carried to as great a distance as one-fourth of a mile.

Septic tanks in one form or another have been tried for many years and are now in regular use in more than thirty cities and towns in the United States, including Plainfield, N. J., Saratoga, N. Y., Mansfield, Ohio, and at numerous institutions. In Europe there are scores of septic tanks in operation, the largest installation being at Birmingham,

the metropolitan district of which includes about 900,000 persons. The septic tanks at Manchester treat about an equal volume of sewage.

Manufacturing wastes have in some instances in this country and in Europe increased the odors from septic tanks, but we see no reason for believing that such trade wastes as cannot be kept out of the sewers at Baltimore would be an important factor in this connection. Sea water contains substances which may combine with others in the sewage and produce odors. It should be rigidly excluded.

Summing up the work performed in the septic tanks, it may be said that about two-thirds of the suspended matter and about one-third of the total organic matter will be deposited. In general the percentage of removal of bacteria in the incoming sewage approximates that of the total suspended matter, although growths of other bacteria in the sludge on the bottom of the tanks may disguise the degree of bacterial removal. This preliminary treatment obviously enables the effluent to be filtered at materially higher rates than the raw sewage with equal results as to quality of filtrate.

With sewage of the composition estimated for Baltimore there would be deposited upon the bottom of the tanks in the neighborhood of 6 cubic yards of sludge per million gallons of sewage in which there would be 90 per cent. or more of water. With favorable management the tanks may be operated so that this sludge will be reduced by bacterial action about one-half, and still further consolidation in the tank to about 2 cubic yards per million gallons. The amount of water in the septic sludge would then be about 85 per cent.

The more important features of managing the septic tanks with reference to reducing the sludge and to disposing of it in the most advantageous manner are next considered.

It is common experience that the depth of sludge accumulated on the bottom of septic tanks varies materially from time to time. Other things being equal, the quantity is greatest toward the end of cold weather and is least at the end of the period of maximum bacterial activity.

In various communities experiences differ in regard to odors in the disposal of septic sludge. Obviously this is due to the differences in the condition of the sludge itself, and the question naturally arises: What are the conditions for the successful disposition of septic sludge without odor? Without entering into a long technical discussion of this question, it may be said that success attends those efforts where the sludge is not removed from the septic tanks until all or nearly all of its organic matter has passed through the putrefying stage and become practically inert. Odors from normal septic sludge seem to be accounted for, largely if not wholly, by the fact that sludge has been removed where there still remains a substantial portion of organic matter in a putrefying rather than in a putrefied condition.

The tanks should be cleaned as far as practicable after or toward the end of a period of maximum bacterial activity when the organic matter of a putrefying nature is reduced to a minimum. In order to obtain the conditions above stated, namely, to have the sludge removed when the putrefactive process is practically completed and not in active operation, crude sewage should not be allowed to enter the septic tank for some time prior to the cleaning of it.

The most successful treatment of sludge by septic process on a large scale is at Birmingham, England, where from time to time nearly all of the sludge is now pumped to a depth of 8 to 10 inches over land where the water is allowed to disappear by percolation and evaporation.

The operation of removing the sludge at the site selected on Patapsco Neck near Back river would involve perhaps once a year or oftener the removal of the fairly clear portion of the contents of each septic tank in turn, and then the flushing of the remaining sludge into drains which would convey it by gravity to adjoining low lands. The main drain or conduit would have branches to allow the proper distribution of the sludge in thin layers as above indicated. Furthermore, banks should be so arranged that this sludge, while drying out to perhaps one-half its volume, would not be washed by rains into adjoining waterways. By keeping the sludge field one-fourth of a mile away from frequently traveled roads it is our judgment that the sludge disposal would create no nuisance.

GASIFICATION. THE ESTABLISHMENT OF SEPTICIZATION

The time required for the development of numerous bubbles of gas upon the surface of the liquid in the septic tank is taken as roughly indicating the period required for the establishment of septicization. As already discussed in connection with the frequency of cleaning of plain sedimentation tanks, this period varies greatly for different sewages, for different seasons of the year, and probably to a greater extent than is generally realized with the different types of bacteria which are at work within the tank. At Columbus, as stated on page 117 of Mr. Johnson's report, the pronounced and continued ebullition of gas was noted after cleaning tanks in about 8 days during the summer and about 17 days in winter. The temperature of the sewage ranged from about 71° to 46°. On the other hand, as stated on page 99 of the Columbus report, settling tanks were cleaned at intervals of 7 to 38 days. At Reading and Worcester still longer periods between cleanings were noted as stated on page 448. Whether bacterial action within so short a period developed

enzymes to the point of maximum efficiency or not is a question upon which we have but little information.

The arrangement of the tank is perhaps of some significance. The deeper the tank, the greater is the volume of gas dissolved in the bottom liquid. Saturation of the liquid at the point of origin of the gas presumably takes place, and various minute bubbles then mass together until a bouyancy is produced sufficient to rise to the surface of the liquid. Different gases appear in varying volumes, depending upon the composition of the substances acted upon and the manner in which gasification is accomplished. It also depends somewhat on the saturation factors of the different gases and combinations between the gases and the clarified sewage.

EFFECT OF SEASONS

As showing the effect of temperature and the season of the year upon the rate of gasification, data secured some years ago at Worcester by Messrs. Kinnicutt and Eddy were computed by the author as follows:

TABLE 67.—PERCENTAGE WHICH THE VOLUME OF GAS PRODUCED EACH MONTH IN SEPTIC TANKS IS OF THE ANNUAL MEAN

January	30	July	140
February	62	August	167
March	48	September	170
April	51	October	116
May	100	November	115
June	148	December	65

These experiments were conducted in a closed tank and the gas measured with a wet gas meter.

During the Columbus tests observations were made upon a septic tank comprising a gas-tight iron cylinder. On page 118 of Mr. Johnson's report he summarizes the evolution of gas during a period from Mar. 4 to June 30, 1905. The results were obtained when the period of flow through this tank, 6 feet in diameter and 14.5 feet long, averaged about 8 hours. The working depth of the sewage in this tank was 5 feet and its capacity 7200 gallons. The summarized results are tabulated as follows:

TABLE 68.—EVOLUTION OF GAS IN SEPTIC TANK E AT COLUMBUS

Month, 1905	Average temperature of applied sewage, degrees F.	Average quantity of gas evolved daily, cubic feet	Percentage which gas was of volume of sewage treated
March	51	29	3.1
April	58	14	1.5
May	61	41	4.4
June	66	50	7.0

Messrs. Clark and Gage, on page 493 of the 1908 Report of the Massachusetts State Board of Health, give data upon gas production in septic tanks at Lawrence. Comparisons are made of the volume of gas with respect to the tank capacity, the volume of sewage passed and the volume of sludge within the tank. No well-defined relationship between the volume of gas formation and other elements above-mentioned was noted. It suggests the importance of a factor upon which our information is extremely meager, namely, the circumstances surrounding the production of enzymes and the conditions which control or arrest their activities. The table in question is as follows.

TABLE 69.—GAS PRODUCTION IN SEPTIC TANK A

	April 21 to May 1	May 2 to May 22	July 10 to July 20	Oct. 4 to Oct. 6
Average storage in tank (hours)	28	21	28	23
Average temperature in tank (degrees)	51	52	74	65
Cubic feet of gas formed per million gallons of sewage passed	6100	8400	11300	6000
Cubic feet of gas formed per 1000 gallon tank capacity	5.3	9.5	9.5	5.3
Cubic feet of gas formed per cubic foot of sludge in tank	0.71	1.27	1.27	0.71

DO SOLUBLE MATTERS GASIFY?

In this 1908 discussion by Messrs. Clark and Gage reference on page 492 is made to the important observation, that gas formation was profuse in bottles which contained sludge, whereas there was absence of such action in bottles where there was no sludge. This absence of gasification in sewage free of sludge is

in line with the data mentioned in Chapter II indicating that bacterial action of vegetative cells seems to proceed in connection with soluble organic matters, whereas the unorganized ferments or enzymes deal with suspended organic matter. On this basis a plausible explanation is found of why ordinary stale sewage decomposes as shown in the data of Tables 24 and 25, while different experiences are noted in true septicization. There is a "lag" after aerobic decomposition ceases and before gasification becomes profuse. It is during this interval that certain enzymes, among other things, are established on a working basis. This is the probable explanation of the time required for septicization to become effective in sewage.

ACTION OF ENZYMES

This subject is a complex one, upon which information has accumulated quite slowly. Dr. Lederer calls the attention of the author to an important article in the *Gesundheits Ingenieur*, January, 1912, by Drs. Guth and Feigl. It is there stated that ferments are present in both crude and stale sewage. The ferments originate partly with animal and partly with vegetable wastes in sewage, are continuously formed by the microorganisms present, and are principally of the character which convert complex suspended organic matters into liquids. Diastase, trypsin, pepsin and lipase, as well as disaccharide ferment, are nearly always present in domestic sewage, with diastase predominating.

Increased cleavage takes place in practice when there is a continuous addition of bacteria or enzymes and when the metabolic products are removed at the same time. In a closed container it is stated that an accumulation of putrescible matters results at first in an enrichment of specific enzymes, but that the ferments become greatly reduced in time. Among other interesting observations is one indicating that the slimy deposit adhering to filtering material is rich in ferments and contains probably oxydases and peroxydases.

KIND OF ORGANIC MATTER

That the quality of the organic matter is of importance is also shown well by data given in the 1908 discussion of Messrs. Clark and Gage. The data may be repeated as shown in Table

70. But there is no definite explanation of why different kinds of sludge produce different volumes of gas. A longer period of time might have affected the results differently. It is also to be borne in mind that besides differences in organic matter there are also differences noted in the seeding of bacteria and complicated biological factors of symbiosis and antagonism.

TABLE 70.—AMOUNT OF GAS PRODUCED BY FERMENTATION OF SLUDGE FROM SEWAGES AND EFFLUENTS FROM TRICKLING FILTERS

Source of sludge	Days	Per cent. organic matter in sludge	Cubic centimeters of gas formed per gram of	
			Sludge	Organic matter
Tannery sewage	61	51	0.00	0.00
Lawrence sewage	26	84	0.34	0.40
Lawrence sewage	21	78	5.80	7.45
Septic tank F	30	46	4.14	9.00
Effluents of trickling filters Nos. 135 and 136	30	44	2.80	6.37
Effluent of trickling filter No. 248	60	45	54.40	121.00

COMPOSITION OF GASES

The best data obtained in America as to the composition of the gases released from septic tanks were secured some ten years ago by Messrs. Kinnicutt and Eddy at Worcester. Weekly analyses were made for a year. The average results are shown in Table 71, and for purposes of comparison there are also included results obtained by Dr. Rideal with the Exeter tanks and also data from the Lawrence Experiment Station obtained by Prof. Gill.

TABLE 71.—PERCENTAGE COMPOSITION OF SEPTIC TANK GASES

	Methane	Nitrogen	Carbon dioxide	Hydrogen	Other gases
Exeter, England	20.3	61.2	.3	18.2	.....
Worcester, Mass.	75.2	17.4	5.9	.3	1.4
Lawrence, Mass.	78.9	16.3	3.4	.....	.....

The Worcester data showed some variation in the content of the gases at different seasons of the year. Methane rose to 81 per cent. during the summer, and carbonic acid or carbon dioxide (CO_2) to 8.85, while nitrogen fell to 8 per cent.

Messrs. Clark and Gage on page 496 of the 1908 Report of the Massachusetts State Board of Health give results of analyses of gas from septic tanks and the fermentation of solids, as follows:

TABLE 72.—ANALYSES OF GAS FROM SEPTIC TANKS AND FERMENTATION OF SLUDGES

Source of gas	Percentage of		
	CO_2	CH_4	N
Septic tank A	3.4	79.0	16.0
Septic tank B	42.2	37.5	19.0
Andover septic tank	9.8	28.7	61.0
Sludge from regular sewage	28.7	1.8	69.5
Sludge from septic tank F	11.7	75.9	12.4
Sediment from filters Nos. 135 and 136	16.2	66.3	17.5
Sediment from filter No. 248	20.5	66.6	12.9

The last Lawrence data are probably not directly comparable with the data in preceding tables. The gases were not collected through a tube or pipe connected with a closed tank, but were obtained by warming the decomposing samples. The gases which were driven off probably showed some influence of the method of collection as it would eliminate the influence of the different coefficients of absorption. Among each other the Lawrence data are probably comparable and indicate that there is a striking difference in composition of gases under different conditions of production.

HYDROGEN SULPHIDE

In practice there are undoubtedly times when hydrogen sulphide is released from decomposing sewage. In America and so far as known in Europe, there are no data indicating that this gas is present in measurable quantities. At Worcester it is stated that careful examinations of large volumes of gas failed

to show the presence of either hydrogen sulphide or carbon monoxide. At Lawrence it is also stated that hydrogen sulphide has never been detected in measurable amounts in the gas of any of the septic tanks. It is stated, however, that the odor of this gas was noted in the decomposition of the sediment from filter 248 which would seem to have been rich in unstable products according to the data in the table. In the gas of septic tank A it is reported that small quantities of carbon monoxide, oxygen and "heavy" hydrocarbons were present. Rather peculiarly the Lawrence data showed no hydrogen in any of the samples, although this is a well known product from the decomposition of some nitrogen-free substances.

While sulphureted hydrogen has shown itself around a number of septic tanks as noted by the discoloration of lead paints and even from the odor of the gas as well as its disintegrating effect upon masonary, yet the only instance that the author recalls where the volume of free hydrogen sulphide has been recorded is in the sewage of Melbourne, Australia. The sewage of this city flows or is pumped for a distance of about 18 to 25 miles and is applied to sewage farms. This project is described in some detail by Mr. W. Thwaites, in the *Transactions of the American Society of Civil Engineers*, Vol. LIV, Part E, pages 214–30. Included among other data are records of certain gaseous constituents of sewage which are copied in Table 73 as follows:

TABLE 73

	Fats, etc., soluble in carbonic dioxide	Carbon dioxide, free	Carbon dioxide, combined	Ammonia, free	Ammonia, combined	Hydrogen sulphide, free	Hydrogen sulphide, combined	Combined carbon dioxide as carbonate
	Grains per gallon	Volumes of gas per 100 volumes of sewage						Grains per gallon
Pumping station, 1	2	10	6	6.0	0.2	0.2	0.9	11
Pumping station, 2	1	6	7	5.5	0.3	0.2	0.5	13
Pumping station, 3	43	9	5	3.2	.....	0.6	0.4	8
Werribee, 1	2	12	8	4.5	0.2	0.2	0.9	15
Werribee, 2	.....	12	7	5.0	0.8	0.3	0.5	14
Werribee, 3	6	12	6	5.4	1.0	1.1	0.4	10
Werribee, 4	4	6	3	6.1	0.1	0.8	0.3	6
Werribee, 5	3	8	2	3.0	1.0	0.2	0.5	4
Werribee, 6	2	10	3	3.5	.....	0.6	0.2	6

The above data bring out another important feature, and that is the relation between free hydrogen sulphide and sulphides of iron and other elements, which properly constitute combined hydrogen sulphide. It is thought by some that the latter, which explains in a large measure the dark appearance of stale or septic sewage due to ferrous sulphide, may be confused in some instances in analytical data with free hydrogen sulphide. The reason of this is that if acid is added in the laboratory it releases the free product from combination and thus gives misleading data. Hydrogen sulphide combines readily with basic constituent of sewage, and thus differs from methane, nitrogen, hydrogen and other gases arising from septicization. The point is worthy of careful consideration.

SIGNIFICANCE OF GAS FORMATION

Speaking generally as to gas formation in the septic process, it may be said that a study of the gas does not give very clear insight at present into the subject. We know in a general way that nitrogen-free substances are attacked in preference to nitrogenous compounds. The carbohydrates and similar compounds ordinarily produce in anaerobic decomposition carbon dioxide and hydrogen. Typical putrefaction produces ordinarily marsh gas and nitrogen, but we do not know to what extent this is related to the work of certain types of bacteria, for instance, B. putrificus.

The so-called methane bacillus may be a single organism or a group of organisms. It is certainly a fruitful field for further study, as is the case with the production of phosphine in septicization.

SCUM FORMATION

In some septic tanks gas ebullition produces a thick scum and in some instances it is sufficient to allow men to walk upon it. In others the tanks show normally a boiling action over the surface of the liquid with but little or no scum. The former case is illustrated by Plainfield experiences and the latter by those of Columbus. At Plainfield gas ebullition is very active and lifts suspended matters to the surface. This is generally characteristic of fresh sewage as compared with stale sewage and also of unscreened sewage as compared with sewage which has been moderately well screened. This is not the whole story, how-

ever. At Plainfield the scum seems to be bound together by molds and other large organisms. Dr. Dunbar of Hamburg thinks that molds are liable to play a far more important rôle than has been thought hitherto. What the facts are we do not now know.

Scum formation is of considerable practical significance in several ways. In the first place much of the solid matter is lifted above the water line and decomposition seems to be arrested to some extent.

On the lower side of the scum the particles seem to be enveloped in gas, at least such is the case at Plainfield. According to Mr. Lanphear, who describes some special experiments in the *Engineering Record* of Jan. 13, 1912, this is of importance in indicating a reduced action as to liquefaction of solid matters. On the assumption that bacteria cannot pass through these gas bubbles, the particles seem to be more or less protected from the influence of the bacteria or of their enzymes which bring about liquefaction.

In some instances changes in velocity of flow may cause the detachment of many of the particles composing the lower portion of the surface scum. In other tanks this may take place quite irregularly or not at all. What the factors are that control it are not clearly known and doubtless they vary in different cases. In all septic tanks, however, there is more or less vertical movement of the deposited solids to the surface and back again to the bottom.

The surface scum may affect appreciably the question of odors. It might indicate a condition more or less resembling that of a masonry cover which would minimize the effect of odor. This does not seem to be so, as some foul liquids and gases reach the upper portion of the scum and there evaporate or volatilize. This is due to the effect of wind or rain, or changing conditions of equilibrium due to the buoyancy of the gas bubbles. At any rate bad-smelling products seem to reach at times the upper surface and by diffusion in the air make their presence felt some distance away from the tank.

DIGESTION OF SOLIDS

From what has been said above as to the irregularities in the process of septicization it is not at all unnatural to expect that the residual product, as measured by the percentage which the sludge found in the tank is of that which has been deposited there,

should be quite variable. That this is so is well shown in Table 74 taken from Profs. Winslow's and Phelps' paper on Investigations of the Purification of Boston Sewage, which appeared in the *Journal of Infectious Diseases*, Vol. VIII, No. 3, page 284, April, 1911.

TABLE 74.—LIQUEFYING EFFICIENCY OF SEPTIC TANKS. PERCENTAGE OF DEPOSITED SOLIDS DISSOLVED

Place	Total Solids	Place	Total Solids	Organic solids
Birmingham, England	10	London, England	41	71
Exeter, England[1]	25	Boston, Mass.[2]	42	81
Manchester, England	26	Glasgow, Scotland	50	.....
Ilford, England	30	Hampton, England	.....	58
Sheffield, England	30	Saratoga, N. Y.	69	.....
Accrington, England	35	Boston, Mass.[3]	72	81
Worcester, Mass.	39	Exeter, England[4]	80	.....
Leeds, England	20–60			
Huddersfield, England	40			

[1] Royal Commission studies.
[2] 1905–7. Rectangular tanks.
[3] 1909–10. Hydrolytic tank.
[4] Early reports from town.

Fifteen years ago or so it was claimed that all solid matters would be liquefied or gasified. Obviously this is impossible with mineral matters. We also know that scum above the water line dries and is not fully humified. Below the water line liquefaction of scum is uncertain, depending upon the influence of gas bubbles. Added to all of these factors are those uncertain elements repeatedly spoken of in Chapter II, namely, the effect of proper seeding as to species of bacteria and the influence of various factors controlling enzymic activities.

Close observation as to the behavior of septic tanks brings out another point of importance, namely, that most septic tanks have occasional periods of abnormally high gasification. The proportion of residual solid matter is unusually small at the close of such periods. The reverse of this is true just before such periods begin. When the Columbus sewage testing station was closed about July 1, 1905, some of the tanks had passed through a violent period of septicization while others had not. Still others were in the midst of such activities. Table 75 contains other American data than those at Boston and Worcester shown in the preceding table.

TABLE 75.—EFFICIENCY OF SEPTIC TANKS IN LIQUEFYING THE SUSPENDED SOLIDS DEPOSITED IN THE TANKS

Place	Tank	Period	Per cent. of total deposits disappearing
Lawrence, Mass.	Tank A	Jan. 1, 1898–Apr. 1, 1904	82.3
Lawrence, Mass.	Tank A	Apr. 1, 1904–Nov. 4, 1908	65.3
Lawrence, Mass.	Tank B	Nov. 15, 1899–Nov. 18, 1901	74.3
Lawrence, Mass.	Tank F	Jan. 27, 1904–Nov. 30, 1907	70.8
Lawrence, Mass.	Tank G	May 23, 1904–Dec. 31, 1905	88.7
Lawrence, Mass.	Tank H	May 23, 1904–Dec. 31, 1905	83.7
Columbus, Ohio	Tank A	Aug. 16, 1904–June 30, 1905	48.0
Columbus, Ohio	Tank B	Aug. 16, 1904–June 30, 1905	28.0
Columbus, Ohio	Tank C	Nov. 22, 1904–June 30, 1905	67.0
Columbus, Ohio	Tank D	Feb. 18, 1905–June 30, 1905	39.0
Columbus, Ohio	Tank E	Mar. 9, 1905–June 30, 1905	50.0
Waterbury, Conn.	Tank 2	Sept. 3, 1905–Nov., 1906	44.0
Waterbury, Conn.	Tank 3	Sept. 3, 1905–Nov., 1906	64.0
Gloversville, N. Y.	.....	May, 1908–June, 1909	54.4
Plainfield, N. J.	.....	Mch, 1910–Jan, 1911	39.1

Note.—In addition to the sludge disappearing by liquefaction and gasification, it is to be borne in mind that the volume also may decrease materially due to a decrease of the water content. The influence of this factor was discussed in the preceding chapter.

QUANTITY OF SLUDGE

This may be taken as the quantity given on page 446 for plain sedimentation, after correction for the amounts of solid matters that are disgorged into the effluent and also for that which disappears by gasification and liquefaction in the septic tanks. On an average about 50 per cent. of the solids are ordinarily assumed to disappear by liquefaction. Widely varying results from this naturally are to be expected, as well illustrated by the Columbus data. There is still to be reckoned with the percentage of water in the sludge. In ordinary tanks this is not likely to be much less than 90 per cent. and it may be more. It varies with the arrangement of the tank, and particularly with the amount of liquid above the sludge that is removed with the accumulation of sludge and scum.

At Plainfield the sludge approximates a little more than 3 cubic yards per million gallons of sewage where there are separate sewers and roughly 100 gallons of sewage per capita.

At Mansfield, Ohio, Mr. Kimberly describes interesting experiences in a special report made to the Ohio State Board of Health for the year 1908, page 520. After four years' service with a sewage flow from about 12,000 people, there were found

in the septic tanks about 1200 cubic yards of sludge. The capacity of the tanks is nominally 1,268,000 gallons and the depth at the flow line about 7 feet. The period of flow through the tanks was roughly 24 hours. The sludge at the end of four years ranged from 2 to 3 feet in depth over the bottom of the tanks. Clogging of the outlet pipes was the cause of cleaning. The sludge had a specific gravity of 1.11 with 80 per cent. of water. In appearance it was black and sticky, not granular.

The sludge removed per thousand persons daily amounted to about 1.9 cubic feet at Mansfield and about 8.4 cubic feet at Plainfield. The Plainfield tanks are cleaned out about once a year and the percentage of water in the sludge is about 90.

At Plainfield it is probable that the digestion of solids on an average is not more than about one-third. At times it is believed to have reached about 40 per cent., but frequently it has been less than one-third. Precise data are not available for Mansfield, but it was much higher than at Plainfield. How far the Mansfield tanks disgorged sludge is not known.

On account of the varying influence of disgorging and of liquefaction we know of no way of forecasting precisely the volume of residual sludge to be expected in single-story septic tanks. It depends somewhat upon the size and arrangement of the tank.

UNLOADING OF SLUDGE

At Plainfield for the first month or so after the septic tanks are put in service following cleaning, the total suspended solids are reduced from an average of about 150 or 160 parts to less than 50 parts. In fact, Mr. Lanphear shows in the *Engineering Record* of Jan. 13, 1912, that monthly averages have been obtained as low as 42 parts in the effluent. When septic action begins it seems to be impossible to keep some sludge and scum from going over into the effluent. The four septic tanks are divided into two pairs which are used in rotation. When one pair shows a marked increase in the suspended matter in the effluent, it is put out of serivce and the other pair used. In this way the average suspended matter in the effluent is probably kept to within about 20 parts per million or roughly 40 per cent. in excess of what the results would be if plain sedimentation were practised. At times, however, it is difficult to keep the suspended matter in the effluent regularly below about 70 parts per million. Better results were obtained with the use

of the tanks in the way described than when all of the tanks were regularly in service, and providing a period of flow of about 18 hours.

This unloading seems to be generally characteristic of the great majority of single-story septic tanks in America. To some extent this may be due to their arrangement. If the tanks were relatively larger and more highly baffled with a relatively longer distance of flow from the influent to the effluent as intended perhaps by Mr. Cameron at Exeter, the effect of this might be materially diminished. Experience at Columbus, however, during 1910 indicates that gas-lifted particles of sludge have a buoyancy which makes them difficult to deposit even when flowing through relatively long tanks.

Mr. Kimberly in his Special Report to the Ohio State Board of Health, 1908, gives interesting data showing the striking effect of this unloading. Table 76 is copied from page 704 of that report, as follows:

TABLE No. 76.—SUSPENDED MATTER IN EFFLUENTS OF REPRESENTATIVE OHIO SEPTIC TANKS

Place	Date	Rate of sewage flow, gallons in 24 hours	Hours' flow	Suspended matter		
				Parts per million		Percentage removal
				Crude sewage	Septic sewage	
Ashland	July 11–12, 1906	150,000	6.3	50	70	–40
Ashland	April 24–25, 1907	375,000	2.5	70	50	29
East Cleveland	June 26–27, 1906	365,000	11.2	210	400	–91
East Cleveland	July 11–12, 1907	390,000	10.4	110	180	–64
Geneva	June 21–22, 1906	181,000	5.2	60	65	–8
Geneva	June 24–25, 1907	204,000	4.6	90	150	–67
Kenton, N. Dist.	October 5, 1906	18,000	24	220	180	18
Kenton, N. Dist.	July 2–3, 1907	17,000	27	70	120	–72
Lakewood	June 12–14, 1906	395,000	18	45	45	0
Lakewood	June 12–14, 1907	1,150,000	6.2	100	140	–40
Mansfield	May 28–29, 1907	1,058,000	23	75	110	–47
Marion	May 23–25, 1906	415,000	24	150	85	43
Marion	Nov. 8–9, 1906	370,000	27	90	140	–55
Marion	April 9–11, 1907	578,000	17	40	45	–12
Sandusky, S. and S. Home	June 5–6, 1906	155,000	17	95	90	5
Sandusky, S. and S. Home	May 8–9, 1907	174,000	15	95	90	5

Note.—Suspended matter to nearest 5 parts below 100 and to nearest 10 parts above 100.

Mr. Kimberly's discussion of these data brings out the point that there is a lack of flexibility in these septic tanks, particularly where there is only one compartment. By rearrangement of the inlet and outlet connections, as well as by baffles and walls to separate the tanks into several compartments, it is feasible to secure better results if constant attention be given. This idea of flexibility and adjustment of tankage to the varying conditions of flow through the use of varying compartments as required, was originally pointed out by Mr. Alvord who discusses this feature in a number of papers, particularly in the *Journal of the Association of Engineering Societies*, Vol. XL, 1907, page 111.

SIZE OF TANKS

In comparing American experiences with those at Exeter and elsewhere it is significant that the American tanks as a rule are relatively much smaller than were the early tanks abroad. In the preceding chapter it is shown for plain sedimentation that tanks of 3 or 4 hours' storage capacity are ample. Septic tanks are larger than this for two reasons. One is to give proper subsiding facilities to the applied sewage when allowance is made for the reduction in the tankage due to the accumulation of sludge. The other reason seems to be to provide dimensions such as will allow gas-lifted particles to subside before the outlet is reached. In practice this may be obtained in some cases, but as a general proposition working plants have not been successful in guarding against unloading in this way.

The smaller volume of sludge per million gallons in weak American than in strong European sewage is a helpful factor in the use of small tanks. This explains in part why septic tanks for several years in America have not provided more than about 8 hours' average flow. An increase in size above this is probably of some benefit, as is also the case with a progressive increase in width of tank towards the outlet so as to reduce the velocity of flow.

At Columbus test tanks holding 8 to 24 hours' flow were studied. As stated on page 326 of the report of Mr. Johnson, there was not enough difference in the behavior of the tanks of larger size to offset the cost of building the larger tanks in practice. No indication of oversepticization was noted.

DISSOLVED OXYGEN CONTENT

With large septic tanks in which septicization is well established, dissolved oxygen is normally absent in the effluent. At Plainfield this is true except for a period of a month or so just after the tanks are cleaned. At Columbus dissolved oxygen is absent normally both in the influent and effluent of the septic tanks.

Mr. Kimberly in his Special Report to the Ohio State Board of Health, 1908, shows that for comparatively small installations dissolved oxygen is quite frequently present both in the influent and effluent of septic tanks. He records interesting data on page 703 of his report from which Table 77 is copied.

From the observations of Mr. Alvord it would seem that the Ohio data are representative of many small plants in the Central West.

TABLE 77.—DISSOLVED OXYGEN IN THE APPLIED SEWAGES AND IN THE EFFLUENTS OF REPRESENTATIVE SEPTIC TANKS IN OHIO

Place	Date of examination	Temp. degrees F.		Parts per million					
		Sewage	Effluent	Maximum		Minimum		Average	
				Sew.	Eff.	Sew.	Eff.	Sew.	Eff.
Ashland	July 11–12, 1906	60	61	3.2	0.0	0.0	0.0	0.7	0.0
Ashland	April 24–25, 1907	47	47	4.3	4.9	1.7	0.0	3.0	3.3
Delaware	May 8–9, 1907	52	52	2.2	1.5	0.4	0.0	1.3	0.4
East Cleveland	June 26–27, 1906	60	59	0.2	0.0	0.0	0.0	0.1	0.0
East Cleveland	July 11–12, 1907	60	60	0.2	0.0	0.0	0.0	0.1	0.0
Geneva	June 24–25, 1907	56	57	3.3	2.0	1.6	1.4	2.2	1.7
Kenton	July 2–3, 1907	64	63	3.9	1.6	2.7	0.0	3.5	0.9
Lakewood	June 12–14, 1907	53	54	6.1	.....	2.2	.....	5.2	4.5
Mansfield	July 25–26, 1906	64	66	2.3	1.8	0.0	0.0	0.6	0.5
Mansfield	May 28–29, 1907	57	55	7.1	1.5	0.3	0.0	2.4	0.8
Marion	May 23–25, 1906	50	51	0.0	0.0	0.0	0.0	0.0	0.0
Marion	Nov. 7–9, 1906	59	58	0.0	0.0	0.0	0.0	0.0	0.0
Plain City	Aug. 1–2, 1906	58	59	7.0	6.2	4.2	4.4	5.0	5.1
Sandusky, S. and S. Home	May 8–9, 1907	65	68	1.4	0.0	0.0	0.0	0.0	0.0

Note.—Results cover periods of 24 to 48 hours as indicated; samples collected at 4-hour intervals.

CLEANING OPERATIONS

Some septic tanks in this country are cleaned once in four or five years and others once in four or five months. Intensive disgorging of sludge may explain why many tanks are not more frequently cleaned. When disgorging or unloading complicates filtration operations, cleaning is practised more frequently than otherwise would be the case.

The shutting off of the influent without cleaning, such as practised at Plainfield, is of some help. If gasification continues for many weeks after fresh sewage no longer enters the tank, this cannot be construed necessarily as an efficient substitute for cleaning. Elsewhere it might work more successfully than at Plainfield.

Thoroughly septicized sludge, such as found when the Mansfield tanks were cleaned and as described by Mr. Kimberly, is substantially free from odor. Unfortunately where septic tanks have been emptied upon sludge beds, in order to remove the water by filtration or evaporation, the sludge itself is not the whole question. Particularly is this so when tanks contain considerable scum. The intermediate stratum of moderately clear sewage, lying between the sludge on the bottom and the scum on the top, is difficult to remove without mixing with such large amounts of suspended matter as to make it difficult to apply it to ordinary filters. When this sewage requires also to be treated as sludge, it materially increases the volume as well as the difficulty of sludge disposal.

At Plainfield, for instance, this is one of the awkward features which has been encountered. Ample area of sludge beds is available so that the quantity of sludge is not particularly bothersome. According to Mr. E. G. Manahan it is the unsepticized liquid which seems to be the source of the principal amount of odor around the sludge beds for a short time after the contents of the septic tanks have been applied to them. In other words, the odor comes from the decomposing and not the septicized organic matter that reaches the sludge beds. The same is true of the scum which frequently contains fecal matters which appear comparatively fresh and show no signs of septicization even to the extent of turning black.

Speaking generally, single-story septic tanks with flat slopes have proved to be unsatisfactory as to cleaning operations. The

deposits may be removed as a rule only with the aid of pushers to force the sludge to the outlet pipes. As described by Mr. Kimberly at Mansfield, it was there found expedient to shovel the deposit into barrels which were lifted out through manholes in the roof.

At Columbus, flushing facilities with water under pressure proved to be quite satisfactory except for the accumulations of mineral detritus near the inlet end. These it is believed should be removed in grit chambers where septic tanks receive the flow of combined sewers. The expense of cleaning has not been great at Columbus, as the operation has normally been fairly simple by discharging into the river at times of flood stages, not only the sludge, but also the overlying liquid.

SLUGE DISPOSAL

The methods described in Chapter XIII cover American practice so far as known.

THE ODOR QUESTION

This is a variable proposition, depending upon a number of local factors with reference to the manner and extent of the decomposition of organic matters, the manner of release of the gases from septicization and other products of decomposition which produce bad odors as outlined in Chapter III. Temperature and climatic conditions are of importance even where the tanks are covered.

Small septic tanks fairly well isolated have not ordinarily given trouble as to odors, although there are exceptions to this rule. Large tanks, dealing with more decomposing organic matter than small ones, usually but not always produce more odor. Covers frequently but not invariably minimize odors. As a rule covers have been employed only for plants located where freezing during severe winter weather was likely to be a serious matter.

Studies of this question in connection with the Columbus and Baltimore projects led to the conclusion that one-fourth of a mile from the tanks was a reasonable limit to the distance at which odors might at times become noticeable to an objectionable degree. Experience shows that ordinarily this limit is more

than ample, but that there are a few occasions now and then where it is insufficient for the ordinary single-story tank for a large city.

Why it is that odors appear to an objectionable degree on a few days in the year and not during the balance of the time is not known. It has led engineers and managers of sewage disposal works to strive hard to improve designs to overcome legitimate objections, particularly under the stress of gross exaggeration by those opposed to the location of disposal works within several miles of their property.

Plainfield Experience.—At Plainfield this matter was investigated with considerable care by the author with the aid of Mr. Lanphear who as an assistant of Messers. Hering & Fuller was in charge of this plant for about two and one-half years, beginning in July, 1908. He was then made manager and chemist of the plant. He prepared a map showing the location of all houses within a radius of one-half mile of the sewage disposal plant and canvassed the views of the property owners with results which are of considerable interest.

The odor question here assumes somewhat more importance than is frequently the case, because the Plainfield disposal works are not isolated to the extent frequently found as such plants elsewhere. From this map it appears that within a radius of one-quarter mile there are 18 dwellings and within a radius of one-quarter to one-half mile there are 141 dwellings. In some measure the odors may have been confused with those arising during the summer from local privy vaults. But, combining the results of these inquiries with the personal observations of Mr. Lanphear during his residence in the cottage of the city near the plant for a period of 2.5 years, it seems reasonable to adopt his summary of the facts as follows:

1. During the winter the odor from the disposal works is very slight and usually absent other than in the immediate location of the covered septic tanks and open sludge beds.

2. During the summer the odor does not ordinarily carry during the day beyond the immediate location of the works, but sometimes it carries 200 yards or more from the septic tanks.

3. On a few evenings in the summer, however, an odor is noticeable at a distance of a quarter to a half mile.

4. At times of greatest odor from the septic tanks, the smell is not noticed for more than a few minutes at a time, with vary-

ing intensity, but it is noticed several times during an evening. It comes in whiffs, so to speak.

5. As to the sludge removed at times of cleaning the septic tanks, an odor has been detected nearly one-quarter of a mile removed from the sludge beds, when the sludge has been removed in the late winter or spring.

When the septic tanks are cleaned during cold weather so that the solid matters are allowed to dry and the putrescible material near the exposed surface is permitted to oxidize to a considerable extent before the warm weather sets in, there is very little odor other than immediately at the sludge beds.

In substance, it may be said that ordinarily there is no objectionable odor noticeable 100 feet away from the disposal works, but that under unusual conditions the odor is noticeable several times that distance, and during the summer of 1910 there were probably six or eight nights when the odor was noticeable a distance of one-quarter mile or more.

In early years the odors were noticeable more frequently, probably due to the exposure of the septic effluent in open channels and on the surface of the primary contact beds, prior to the changes which allow these filters to be filled from below without exposing the liquid to view. Periods of most noticeable odor are characterized by very damp or "muggy" weather, when the gases presumably do not rise as high in the atmosphere as is usually the case. There was some more odor in 1911 than in 1910.

In connection with the question of odors, it is well to bear in mind that during the past ten years a very large proportion of the 141 houses within a radius of one-half mile of the plant have been built.

Undoubtedly the Plainfield septic tanks have the reputation of behaving badly, although this is true on very few occasions as to odor. In fact, the author during repeated visits to the plant has never personally happened to be present when the odors were noticeable more than 100 yards away.

Columbus Experience.—At Columbus much has been said of offensive odors at the large installation of uncovered septic tanks and sprinkling filters. Here the odors ordinarily are not noticeable 1000 feet away from the plant, but there are a few occasions when the odor is noticeable as far away as one-half mile. This plant too has been the victim of considerable misunderstanding and misinformation. In *Engineering News* of Dec. 1, 1910, a

summary is given of a remarkable report on the Columbus situation by Mr. John E. Hill, Assistant Engineer of the Board of Estimate and Apportionment of New York City. Mr. Hill visited this plant on Nov. 21 and 22, 1909. At that time the main intercepting sewer in Columbus was being cleaned and much sewage was being discharged into the Scioto river, then at a very low stage. Mr. Hill states that as he proceeded to the works from the city across the Frank road bridge and southward along the railroad spur, he caught the odor from the purification works suddenly and strong at a distance of about three-quarters of a mile from the works. He states that "there was no doubt about the character and offensiveness of this odor. It was characteristic of the septic tank and for the moment was nauseating. For a distance of about three-eighths of a mile this odor was dully sickening; from this point it decreased in intensity and intolerability until a point to the windward of the septic tanks and in the vicinity of the filter beds was reached where it was not intensely offensive. I tested this peculiarity several times with the same result."

Reference is then made by Mr. Hill to supplementary testimony from inhabitants in the neighborhood and this he stated to the effect that "under certain conditions intolerable odors were appreciable over a limit of three-quarters of a mile to nearly one and one-half miles from the works and might honestly be considered a nuisance up to the limits of these distances."

The Frank road bridge is 1822 feet north of the septic tanks and four-tenths of a mile north of the center of the north end of the filters. At the Frank road bridge is the terminus of a private sewer which brings to the river the untreated wastes from the Columbus Packing Company's plant. They do not reach the current of the stream and frequently much offensiveness is noted from the stagnant pool of these wastes just north of the bridge in question.

At the time of Mr. Hill's visit the work of cleaning the main intercepting sewer was under way and the sewage from the entire north end of the city was discharging into the river without treatment. The river was then very low and during much of the time was without dissolved oxygen, as noted in Messrs. Scott's and McDowell's discussion of Mr. Gregory's paper on the Columbus Sewage Works, page 331, Vol. LXVII of the *Transactions of the American Society of Civil Engineers.*

In *Engineering News* of Jan. 25, 1912, page 171, a quotation is given from the Third Annual Report of the Division of Sewage Disposal at Columbus, Mr. W. W. Jackson, Superintendent, as follows:

> The purification works has been criticized, on account of the odors present, in a report by Mr. John E. Hill to the New York Board of Estimate and Apportionment. It is to be regretted that a man so ignorant of the art of sewage disposal should have been selected for this investigation. His statements regarding the extent of the zone of positive nuisance and the intensely nauseating effect of the odors are absolutely false, and his failure to qualify other statements shows a lack of comprehension of the problem which is an injustice to the Columbus works and misleading to other municipalities. It cannot be denied that an odor is present at the purification works, sometimes rising from the tanks, but chiefly emanating from the filter sprays, but that Mr. Hill's statements are distorted will be apparent to anyone who visits the plant. While the warm-weather sewage is stale before reaching the plant, it is expected that the changes proposed for the preliminary treatment, together with the aeration of the influent, will ameliorate this objectionable feature.

Mr. Kimberly in his Special Report to the Ohio State Board of Health, 1908, page 701, discusses in a valuable way the question of odors. In many cases the septic effluents from the small Ohio plants are aerated. This is stated to create an unnecessary nuisance from odors, especially in the case of a strong sewage. Further, aeration causes a considerable loss both in available head and temperature of the sewage which is objectionable during the winter as to the efficiency of subsequent treatments. The indications were that there was no special benefit to be derived from aeration sufficient to offset the disadvantages as to objectionable odors and loss of head and temperature.

Mr. Kimberly further states that odors have not been especially pronounced near the Ohio septic tanks (excluding Columbus works) and that there was no cause for criticism at distances of 100 to 200 feet from the septic tanks. Further, the statement is made that the odors arose chiefly from the scum and that there appeared to be but few objectionable conditions to be traced to the effluent.

Mr. Alvord informs the author that while some of the septic tanks with which he is familiar in the Central West have proved

somewhat bothersome at times, there are a great many that behave satisfactorily and give no cause of just complaint as to odors.

COVERS

Covers for septic tanks tend to lessen the likelihood of odors. This seems to be due to a reduction of the disturbance of the surface by wind, and of the chances for the odoriferous products to travel away from the tanks without dispersion, mixing or oxidation. Wind brakes are probably about as effective as covers.

B. SEPARATE TANKS OR RECEPTACLES FOR SLUDGE DIGESTION

The employment of septicization in separate tanks for the treatment of sludge, removed at frequent intervals from plain sedimentation tanks, has much historical significance. It is availed of in a number of important works now in service or about to be put in service. Improvements due to the use of two-story septic tanks seem to have decidedly limited the extent of the development of this arrangement. But in outlining the history of modern methods of sewage disposal, it is important to review briefly the experiences with this procedure.

This idea was first studied at the Lawrence Experiment Station by Mr. Clark. Its historical development was recently summarized by Mr. Gage in his discussion of Mr. Saville's paper on pages 29–31 of the *Journal of the Association of Engineering Societies*, Vol. XLVII, July, 1911. The essence of Mr. Gage's remarks is as follows:

A paper by Mr. H. W. Clark before the American Public Health Association was read at the Minneapolis meeting on October 31, 1899, and in it Mr. Clark stated: "I believe a modification of the septic tank could be constructed, intended to treat only the matters in suspension in the sewage and settled out daily while passing through ordinary settling tanks, flushing this accumulated sludge when necessary into a septic tank." The origin of this idea is thus stated by Mr. Clark on page 422 of the Report of the Massachusetts State Board of Health for the year 1899. "The observation that the stronger the sewage entering a septic tank the greater is the removal of organic matter suggests the idea that, where exceedingly large volumes of sewage are to be purified, as in the case of the sewage of a large city, this sewage could be passed through ordinary settling tanks, so constructed that the sludge settling

to the bottom of these tanks could be flushed into a septic tank and this sludge alone be treated by septic action, instead of attempting to treat the whole of a city's sewage. Following up this idea, a septic tank was put in operation during November, 1899, to receive the strong sludge from settled sewage." This tank was a double-deck affair, with a settling tank on top and a septic tank for the sludge below. Sewage was allowed to settle for four hours in the upper tank, the supernatant 90 per cent. was then drawn off and the remaining 10 per cent. containing the settleable sludge was allowed to flow into one end of the lower tank, an equal volume of liquid being displaced through an outlet at the opposite end. The heavy sewage entering the sludge tank contained on an average about 14,300 pounds of suspended matter per million gallons, or about seven times as much as the regular Lawrence sewage. The volume of this concentrated sewage entering the sludge tank daily was about one-fifth of its capacity during the greater portion of the time. About 82 per cent. of the suspended matters entering the sludge tank were deposited, and about three-fourths of the matters so deposited were destroyed within the tank. The dried sludge from this tank after about one year of operation contained about 46 per cent. of mineral matter and about 54 per cent. of organic matter. After about two years of operation, the amount of sludge held in the tank had accumulated to such an extent that it was difficult to keep it in operation, and it was evident that the capacity of the sludge tank was too small to care for the amount of suspended matters which were entering it. The daily admission of sludge into the tank was therefore stopped and the tank with its contents was allowed to stand quiescent for a period of four months, during which time the volume of sludge in the tank decreased more than one-half. A second tank of this type was operated at Lawrence from 1904 to 1907, but the concentrated sewage entering the sludge tank did not contain such a large proportion of suspended matters as in the earlier experiments. The results with this tank were very similar to those obtained with the earlier tank, so far as deposition and destruction of sludge were concerned, but as the tank was of much larger capacity in proportion to the amounts of suspended matters entering daily, clogging did not occur.

Another septic or "hydrolytic" tank, started at Lawrence in November, 1899, was an upward-flow tank completely filled with broken stones, with the idea of providing a largely increased surface for the deposition of sludge. I mention this here, because it was from the reports of the operation of these two early Lawrence tanks that Dr. Travis drew his ideas which he combined and developed into the well-known Travis or Hampton tank. While Dr. Travis has freely and fully acknowledged the source of his inspiration, this fact has been entirely overlooked by the majority of American writers on the subject of sewage disposal.

Mr. M. N. Baker on page 65 of his book on "British Sewage Works" confirms the above statements as to the acknowledgments made by Dr. Travis to the early Lawrence studies.

This method attracted but little attention in America prior to the appearance of Mr. Baker's book in 1904. It was not considered necessary to resort to this arrangement and for several years this remained the view of the author and others connected with this line of work. This was the period when the best practice endeavored to secure the benefits of septicization in single-story tanks along the lines described in the Baltimore report as already quoted.

A small two-story tank was built by Messrs. Alvord and Shields in 1900, with others since then by Mr. W. S. Shields as stated by him in the *Municipal Journal and Engineer*, Mar. 8, 1911.

The first large American project in which separate sludge chambers were recommended is detailed in a report of Mr. Hazen to the city of Paterson, N. J. In 1906 he recommended a series of separate sludge tanks into which the deposits from plain sedimentation basins would be removed and in which the sludge might become treated to an extent where it would be no longer odoriferous. This arrangement is described in the *Engineering Record* of Aug. 11, 1906, page 145.

At Reading and at Kings Park mention has been made in the preceding chapter of efforts to septicize sewage in lagoons and trenches. They have not been successful from the standpoint of gasifying solid organic matters to the extent which other arrangements have shown to be feasible. The Kings Park plant, upon being enlarged to serve an increase of 50 per cent. in contributing population, is now being changed to a two-story tank with sludge drying bed.

This procedure is availed of at Baltimore in connection with a small plant at Forest Park in the suburbs of the city and is one of the features of sludge disposal for the main city plant on Back river. (See *Municipal Journal and Engineer* of Dec. 14, 1911, page 756.)

As previously stated, there has been some comment as to odor from the Forest Park plant, although Mr. Hendrick considers that the results have been reasonably satisfactory.

It is at the sewage testing stations at Chicago and Philadelphia where evidence has been secured that does most to indicate that this method is to be superseded by later improvements. Mr.

Pearse states that he has encountered some difficulty with odor and also in getting a substantial portion of the sludge digested. The ebullition of gas lifts much of the solid matter above the flow line where it dries to a hard scum (see Fig. 32, page 455). In fact, it was necessary to remove much of the dried material by means of forks. The arrangement is spoken of disparagingly in the 1911 Philadelphia Report, page 175.

In conclusion it may be said that this procedure when carefully applied overcomes some of the disadvantage of having both sedimentation and septicization take place in the same tank. In particular does it guard against the settled effluent being impregnated with gas-lifted particles of sludge. On the score of complete and satisfactory sludge digestion it is not a success. For small plants it has advantages, but it attracts attention chiefly as an intermediate step leading to the still greater advantages afforded by two-story tanks.

C. THE TWO-STORY HAMPTON OR TRAVIS TANK

The early history of two-story tanks is somewhat obscure both as to patent relations and to the merit to be attached to them. In 1891 there was patented in England the Birch sedimentation tank in which baffles or sloping partitions were provided by which the sludge could be separated in a space below the intermediate walls. Intensive bacterial growths to bring about septicization through enzymes were then practically unknown We are unfamiliar with the detail work accomplished in the Birch sedimentation tank.

Later, Dr. Travis and his associates at Hampton, England, devised the two-story hydrolytic or septic tank which was patented and first put in service in the year 1903.

In the Hampton tank is to be found the first marked step in advance along practical lines as a result of the Lawrence studies to avail of septicization in a compartment separated from the sedimentation chamber. It was the custom at least for some years to allow about four-fifths or nine-tenths of the sewage flow to pass through the upper compartment, with the solids settling through slots automatically into the sludge digestion chamber below. The remainder of the sewage flow was allowed to pass through the lower or digestion chamber with the two streams uniting at the effluent weir. It is understood that Dr.

Travis has minimized the flow of sewage through the lower chamber, and in this way practically equals the Imhoff tank.

Considerable progress has been made with the installation of Hampton tanks in Europe. In America there are none that we know of. Compared with the Imhoff tank, it is much less familiar to Americans, and American engineers who have visited European works are of the opinion that there is more likelihood of odor around the Hampton tanks than the Imhoff tanks.

Whether or not there are appreciable advantages in allowing some of the sewage to pass through the lower tanks is a question

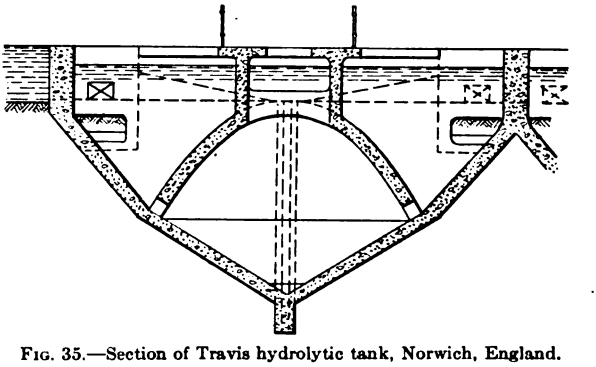


FIG. 35.—Section of Travis hydrolytic tank, Norwich, England.

upon which there has been dispute. As this subject is now understood in America, the prevailing view is opposed to allowing the effluent of settling compartment to be influenced at all by the contents of the digestion chamber.

Associated with the Hampton tanks has been the development of the de-solution theory which means that along physical lines alone it is feasible to eliminate a large share of substances of an unstable character by the removal of colloidal and other matter not in solution. To utilize in practice the benefits of de-solution as distinguished from biological purification, the Hampton tank has been associated with colloidors or arrangements of slats or other devices upon the surface of which adhere the finely divided suspended matters or colloidal substances. How the arrested particles may be removed with a minimum of anaerobic action is a question upon which final evidence is not before us. So far as Americans now know from literature and observation, this device is less likely to give satisfactory

service than is the Imhoff tank. If this statement is incorrect, its modification will have to depend upon future data.

Fig. 35 shows a view of a Travis tank as installed at Norwich, England, by Mr. Arthur Collins and described in *The Surveyor* of June 5, 1908. It differs from the early tank at Hampton in reducing practically to a minimum the passage of decomposing sludge from the lower to the upper compartment. Dr. Travis claims that this tank, built under his patent, can show all the advantages claimed for Dr. Imhoff's modification of the Hampton tank.

D. TWO-STORY EMSCHER OR IMHOFF TANKS

In the Emscher district of western Germany tests were made with the Travis tank beginning early in 1906. Modifications were soon made which had for their specific purpose the prevention so far as possible of sewage in the upper or sedimentation chamber from coming in contact with any of the contents of the lower chamber, in which is progressing the digestion of solids or sludge which automatically reach there through the slots in the walls separating the upper from the lower story or compartment. From that time this two-story tank has been the subject of the most careful study in the practical operations of the Emscher district by Dr. Karl Imhoff and his associates. It is regarded in America by those best informed as the device affording by far the most advantageous conditions not only for the clarification of sewage, but also for the digestion of the sludge, so that the latter may be disposed of economically and without odor. The credit of early recognition of the merit of this arrangement of a two-story tank for solution of American problems is largely due to Mr. Rudolph Hering.

Credit to Mr. Clark of Lawrence and to Dr. Travis should not be forgotten when considering the Imhoff tank.

The Imhoff tank is not a cureall by itself for a wide range of sewage problems. In fact, it is not a complete method of sewage disposal except in conjunction with adequate facilities for dispersion of the effluent in water. It will not remove dissolved or finely suspended or colloidal matters. The removal of total organic matter is not ordinarily more than 25 to 35 per cent., while the removal of the unstable or highly putrescible substances is somewhat less than this percentage. Nothwithstanding its

inability to displace filtration or sterilization methods under numerous conditions and that without careful management it is not an absolute guarantee against noticeable odors at all times, particularly when it is first placed in service, it stands out conspicuously, in the opinion of the author, as the most important step in advance in the art of sewage disposal during the past five years.

EXTENT OF USE

This device was first placed in regular operation at Recklinghausen, Germany, in February, 1907. The plant serves a population of about 30,000 inhabitants. Fig. 36 shows a view

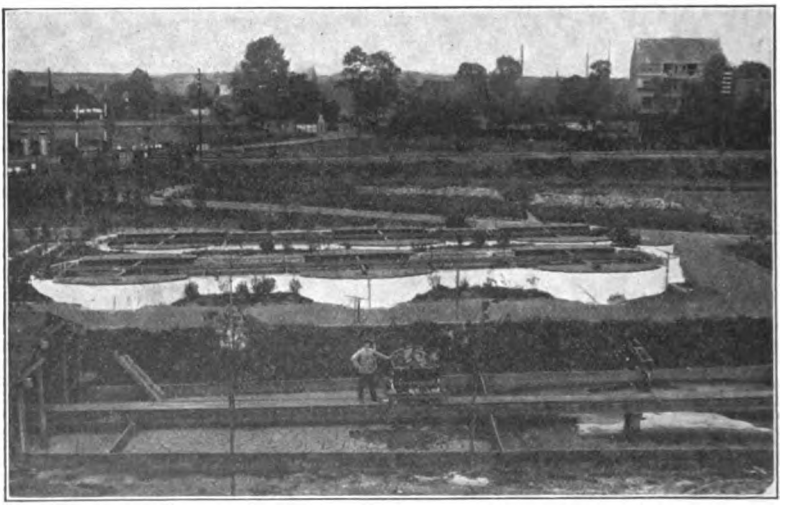


FIG. 36.—Imhoff tanks at Recklinghausen.

of this plant furnished by the courtesy of the Pacific Flush Tank Company, American representatives of Dr. Imhoff. Since that time some 12 plants have been installed in the Emscher district, and at least 50 plants either installed or under construction elsewhere in Europe. The history of improved sewerage and sewage disposal in the Emscher district is well outlined by Mr. Saville in his paper before the Boston Society of Civil Engineers in December, 1910 (*Journal of the Association of Engineering Societies*, Vol. XLVII, July, 1911).

In America experimental plants have been studied at Philadelphia, Pa.; Chicago, Ill.; Columbus, Ohio; and Worcester, Mass.

Plants of this type have been built or are under construction at the beginning of 1912 at Philadelphia, Pa.; Madison-Chatham, N. J.; Atlanta, Ga. (Three separate plants); Batavia, N. Y.; Chambersburg, Pa.; Winters, Calif.; Rome, N. Y.; and Winchester, Ky.

The plant at Madison-Chatham, N. J., serves jointly the boroughs of Madison and Chatham, each of which has just built a new sewer system. Connections were first made with this plant through the Madison sewers beginning Nov. 2, 1911.

Plants of this type have been recommended in several dozen instances so that it may be fairly said that this device has established for itself a well-recognized standing as embodying the most successful steps in the process of the preliminary treatment of sewage by means of clarification, and particularly as to the disposal of the sewage sludge in an inoffensive condition at minimum expense and with a minimum likelihood of odors.

It is not intended to convey the impression that this tank does away with the merit of all single-story tanks or that there is a great economy in its construction cost. In fact, owing to its relatively great depth it is a more expensive tank to build than the older type of single-story tank. Yet it is believed that the increased cost of construction is fully warranted by the benefits secured along the lines above described. Mr. Wisner in his Chicago report compares the local per capita cost of tanks of different types as follows:

TABLE 78.—COMPARATIVE COSTS OF TANKS

Type of tank	Nominal period of settling	Gallons per capita daily	Cost per capita
Emscher	3 hours[1]	200	$1.44
Dortmund	4 hours[1]	200	0.84
Straight flow	8 hours	200	0.77
Straight flow	6 hours	200	0.58

[1] In both these periods the sludge storage is not calculated in determining the nominal period of settling.

CONSTRUCTION FEATURES

Imhoff tanks have been built of three distinct types known as the radial flow tanks, horizontal flow tanks with rectangular digestion chambers, and horizontal flow tanks with circular digestion chambers. The last seems to be the most popular one in Germany for large installations, and is illustrated in Fig. 37. Kindly furnished by the Pacific Flush Tank Company.

American engineers have not taken kindly to this style of design for large installations, but have preferred as a rule a design which is rectangular in plan for both the top and bottom compartments. Fig. 38 shows such a design for the Madison-Chatham plant made in the office of the author. The cover was not shown on the original drawings, but was added at the

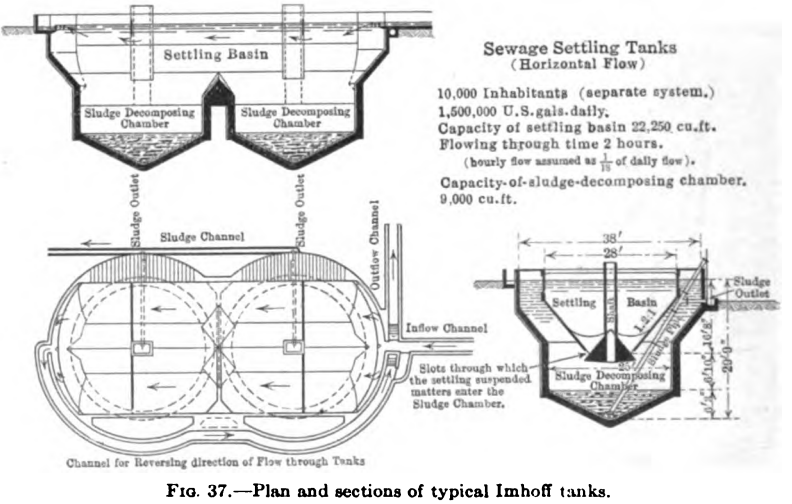


FIG. 37.—Plan and sections of typical Imhoff tanks.

request of the local committee in fulfillment of a pledge to neighboring property owners to obscure the sewage from view while in an unpurified state.

In Germany the radial flow tank is considered most applicable for small installations. In Fig. 39 is shown a tank of this type designed in the office of the author for the borough of North Plainfield, N. J.

In the flow of combined sewers grit chambers designed as stated in Chapter XIII should preferably precede these tanks.

Screening is not practiced in the Emscher district except with coarse bar screens with about 2-inch openings. With fresh

sewage scum will form and this must be carefully removed from time to time.

Fig. 40 shows a view of the Imhoff tanks at Batavia, N. Y., furnished by the courtesy of Mr. John H. Gregory.

Sedimentation Chamber.—An average period of flow of about 2.5 hours seems to be the prevailing capacity of the upper compartment. With the stronger sewages of Europe this period is

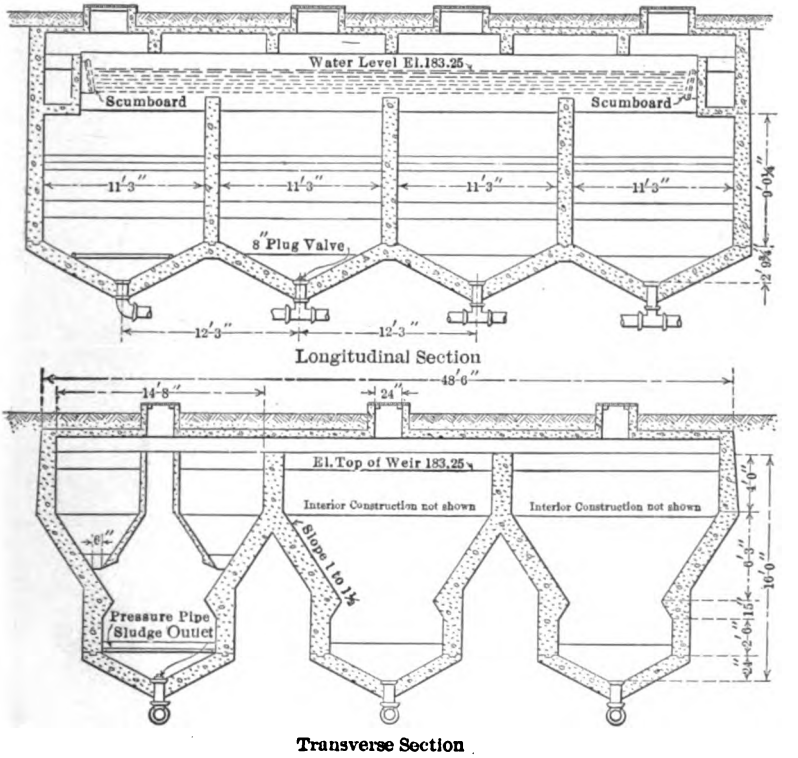


FIG. 38.—Two-story tanks at Chatham, N. J.

much smaller, in some instances being less than one hour. The lineal velocity for horizontal flow tanks ought not to exceed for a maximum about 12 millimeters or 0.5 inch per second, or 2.5 feet per minute. Some improvement in sedimentation would probably result with a velocity which never exceeds about two-thirds of this figure, for reasons explained in Chapter XIII. With radial flow tanks the upward velocity from beneath the

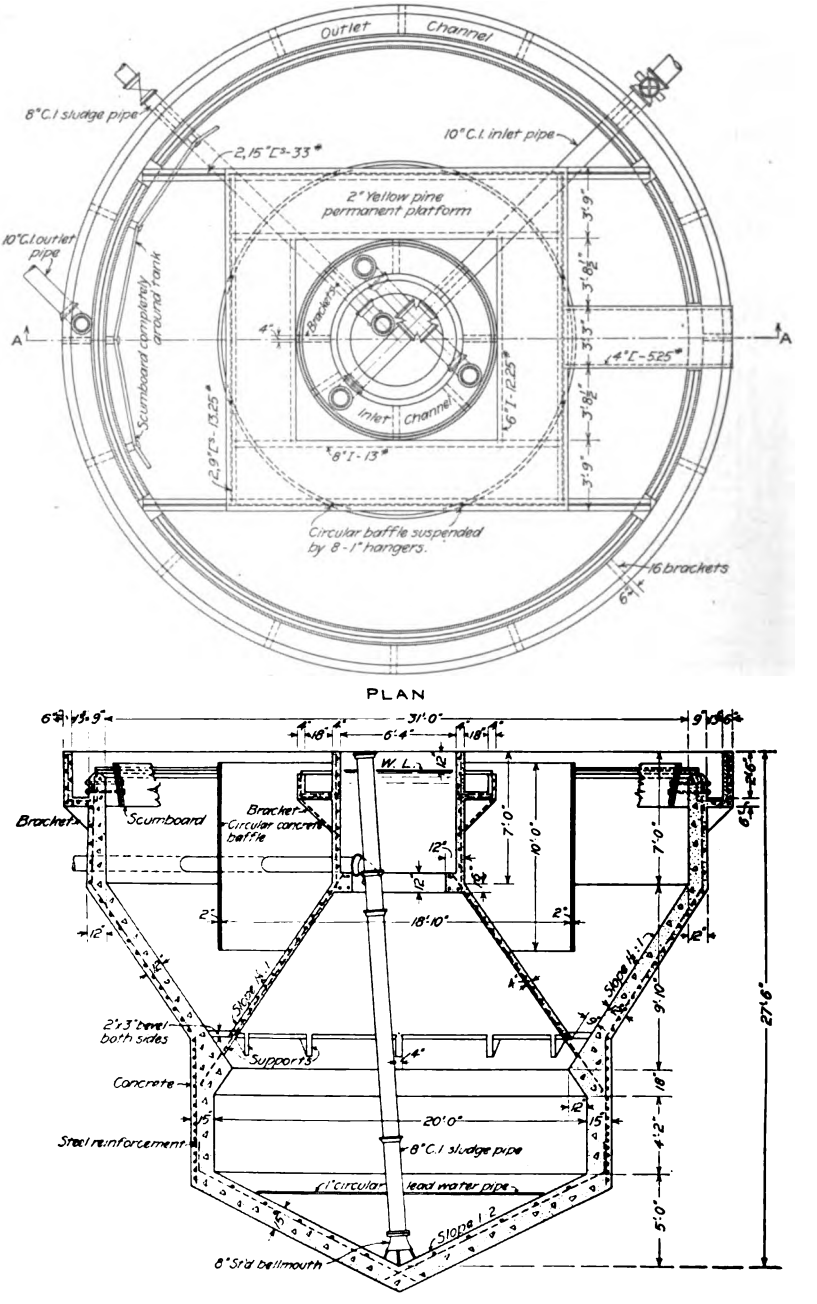


FIG. 39.—Two-story tank for North Plainfield, N. J.

circumferential baffle should be not more than about 0.5 millimeter or 0.02 inch per second, or 0.1 foot per minute.

The sloping partitions to facilitate the automatic discharge of the sludge into the compartment below are currently made about 1.2 or 1.5 vertical to 1 horizontal. Scum boards should be provided for the detention of floating matters, unless the sewage is efficiently screened.

The inlet and outlet connections should be arranged to prevent

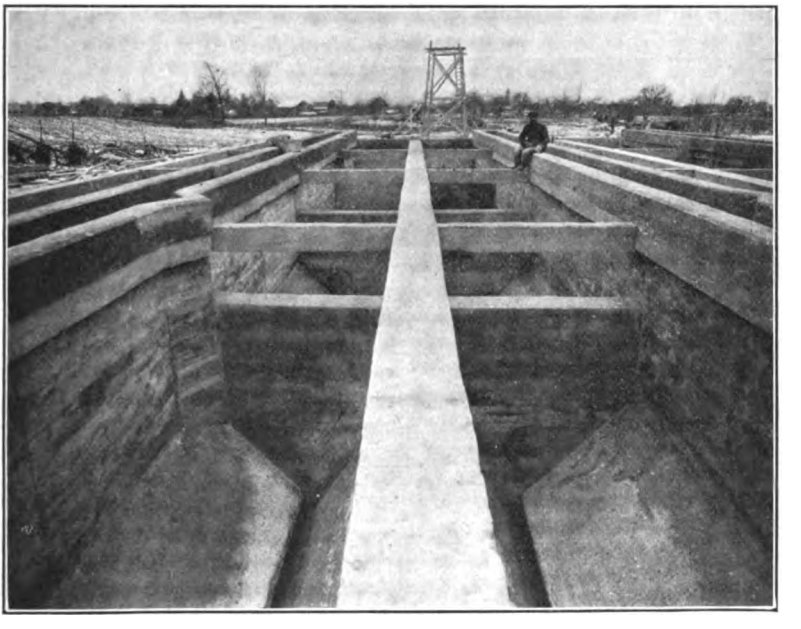


FIG. 40.—Two-story tank at Batavia, N. Y.

depositing velocities, and also to guard against dead spaces within the settling compartment; in other words, to promote the uniform flow of sewage through the full cross section of the settling compartment. Every effort should be made to guard against solid matters remaining in the sedimentation compartment and decomposing there. Scum should be removed at frequent intervals and any greasy deposits adhering to the walls or sloping partitions at the bottom should be pushed through the outlet slot with the aid of a rubber straightedge or similar device. Any pipes or structures passing through

this compartment should have their upper surface pointed up with steep slopes so as to guard against deposits accumulating thereon. The surfaces of the walls of the sedimentation compartment are preferably made of concrete and should be as smooth as practicable.

It is advantageous from the standpoint of digestion of the sludge to be able to reverse the direction of flow through horizontal flow tanks so that at each end at intervals of a month or so there may be a rotation in the character of deposited solids in the lower compartment. State Boards of Health do not take kindly to this idea unless steps are taken to guard against easy means of by-passing the sewage flow to some convenient watercourse.

Covers are not necessary unless in severely cold climates. They make more difficult the removal of scum and the cleaning of the walls, slopes and bottoms of the sedimentation compartment.

Digestion Chamber.—In most American designs the capacity of the lower compartment is sufficiently large to store an accumulation of some six or eight months' production of sludge. This is usually on the basis of about 80 per cent. of water. Conditions as to foundations and expense of construction modify somewhat the advisable capacity of a digestion chamber, and to some extent this is true with respect to the influence of long periods during severe winters when it is impossible or difficult to operate properly the sludge disposal devices required for the emptying in part of these chambers.

It is particularly important to see that the slot connecting the upper with the lower compartment should be arranged to minimize the passing of sludge or gases from the lower to the upper compartment. The slot should be 6 to 12 inches wide and have an overlap of three inches or more, measured horizontally. In fact, this detail alone distinguishes specifically the Imhoff from the Travis tank, and as stated above the splendid work of Dr. Travis should by no means be ignored because of this improvement by Dr. Imhoff.

The lower compartments are provided with vents through which gases of decomposition escape and in which are to be found more or less scum and gas-lifted sludge. The amount of scum will no doubt vary with different plants, depending among other things on the quality of the sewage, particularly as to the degree of comminution of the suspended matter and the amount of

screening which it has received. The vents for the escape of gas and the accumulation of scum are currently designed in America with an area of about 10 per cent. of the total superficial area of the tanks.

In some cases it will be necessary to remove this scum in the vents from time to time. This may be done by shovels with the scum delivered to the sludge-drying beds where it may be well mixed with dried sludge. Some attempts have been made to provide pipes or troughs for removing the scum in the vents so as to deliver it to the sludge beds in the same way as the contents of the digestion chamber. There is some doubt as to the success of this detail in practice.

The floor of the lower compartment is composed of a series of ridges and valleys with sludge-removing pipes located in the sumps or valleys. The slopes of these ridges need not be more than 1 vertical to 2.0 horizontal. If the sludge shows difficulty in starting to flow, it may be well stirred up with the aid of water under pressure applied through perforated piping. Such a water pipe has probably other advantages in stirring up the contents of the digestion chamber under some circumstances.

The sludge removal pipes should be not less than 8 inches in diameter and should have an outlet connection about 5 or 6 feet below the flow line of the upper compartment. Then on opening a gate the sludge will ordinarily flow by gravity to a pipe drain leading to the sludge-drying bed. The well-ripened sludge from the lower compartment, after it has been say from 3 to 8 months under anaerobic decomposition, is black and gelatinous due to ferrous sulphide. In it are many entrained gas bubbles, the amount depending largely upon the depth of the tank. This sludge will not flow as freely as ordinary sewage and the slopes should be at least 1 in 30 and preferably 1 in 20 for an ordinary 8-inch pipe.

Some trouble may be expected if the interior of the pipes is not cleaned following their use in the removal of the contents of the lower compartment. Provisions should be made for flushing or rodding out the pipes or else open drains where feasible should be used.

The drainability of the sludge is due largely to the entrained gases which increase with the depth of the tank. While great depth should not necessarily mean an upsetting of the basis of a design that is controlled by questions of economy as related to

quicksand and rock excavation, it is a factor to be taken into account in considering the proper construction and operation of the plant as a whole. A tank 15 feet deep is practicable, but the sludge from it cannot be dried so readily as that from a 30-foot tank.

If a gravity flow to the sludge-drying beds is not feasible, care should be taken to use a pump without suction lift, as that frees the entrained gas and eliminates one of the substantial benefits accompanying the disposal of sludge from tanks of the Imhoff type. Centrifugal pumps are not suitable.

Computation of Capacity of Sludge Compartment.—Mr. Allen on page 227 of his book gives a formula for computing the size of the sludge compartment which we have modified to read as follows:

If we assume 80 per cent. moisture in Emscher sludge and 90 per cent. in freshly settled sludge, the latter will occupy twice the volume of the former, and an equal mixture will occupy 1 1/2 times the volume of Emscher sludge when completely digested. Therefore, if:

v = flow of sewage in gallons per capita per day.
V = total daily flow of sewage.
P = population served, and expressed in thousands.
D = days' retention of sludge.
C = effective capacity of digestion chamber in cubic feet.

Then, for combined sewage, $C = 10.5 \frac{DV}{v} = 10.5\ PD$, and for separate sewage, $C = 5.25 \frac{DV}{v} = 5.25\ PD$.

Sludge-drying Beds.—These beds consist of about 10 inches of graded gravel, cinders or coarse sand with a thin surface layer of fairly fine sand. They are underdrained at intervals of about 10 feet. Sludge is spread over them to a depth of about 1 foot or so. Owing to the entrained gas bubbles the solids seem to rise to the surface and the liquid passes down through the bottom, leaving in dry weather a spadable product in less than a week. As removed from the digestion chambers the percentage of water ranges from about 70 to 80, depending upon the depth of the tank and other factors connected with the digestion. After drying to a spadable condition, the percentage of water ordinarily ranges from 55 to 60. The area of sludge drying beds should be per thousand population about 350 square feet in the case of a separate system of sewers. With combined sewers the street wash and also trade wastes may increase this

required area from 50 to 100 per cent. and even more, if the trade wastes are abnormally conspicuous in point of solids. If shallow tanks (15 feet) are used these areas should be increased 50 to 100 per cent.

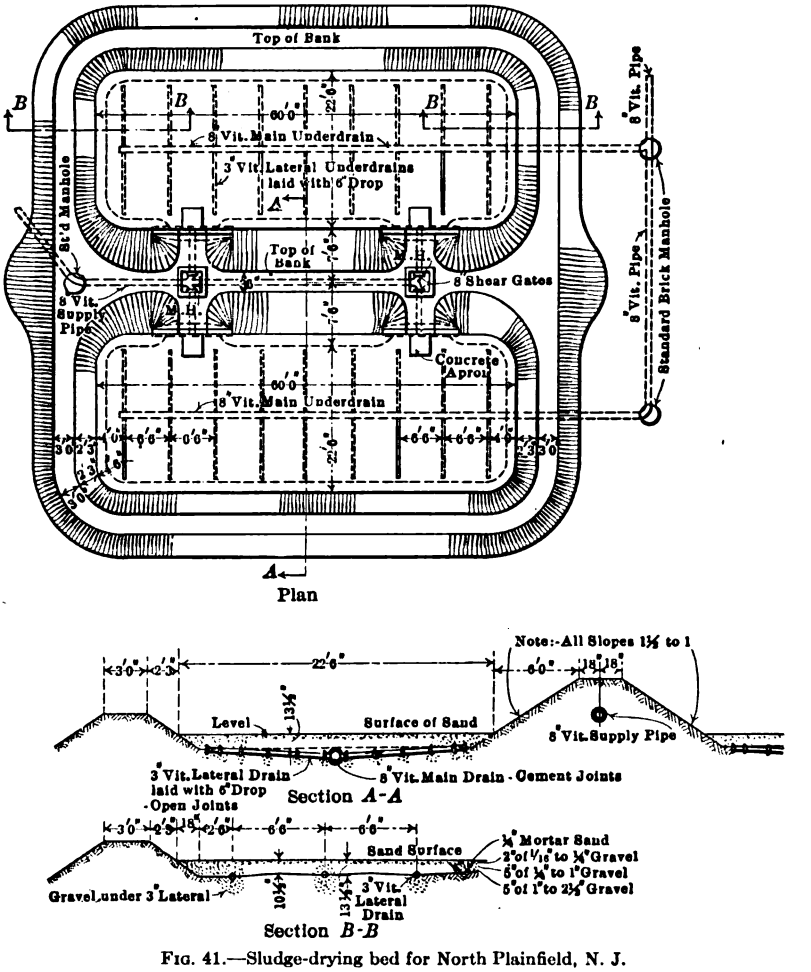

Top of Bank
8" Vit. Main Underdrain
3" Vit. Lateral Underdrains laid with 6" Drop
8" Vit. Supply Pipe
Standard Brick Manhole
8 Shear Gates
Concrete Apron
Plan
Note:-All Slopes 1½ to 1
Level
Surface of Sand
8" Vit. Supply Pipe
3" Vit. Lateral Drain laid with 6" Drop -Open Joints
8" Vit. Main Drain - Cement Joints
Section A-A
Sand Surface
¼" Mortar Sand
2" of 1/16" to ¼" Gravel
5" of ¼" to 1" Gravel
5" of 1" to 2½" Gravel
Gravel under 3" Lateral
3" Vit. Lateral Drain
Section B-B

FIG. 41.—Sludge-drying bed for North Plainfield, N. J.

Fig. 41 shows current practice in the arrangement of sludge-drying beds. State boards of health have shown some inclination to view with suspicion such shallow beds unless they have good reason to believe that crude sewage cannot be applied to them intentionally or by accident. Fig. 42 shows a view of the

beds at Atlanta, as furnished by Mr. Hansell. Cars are provided on a permanent track to facilitate removal of the dried sludge.

The dry sludge is porous, more or less resembling garden soil and supports vegetation. It may be used for filling or fertilizing purposes. It is considered preferable for the latter purpose to use fresh sludge, as it promotes porosity of the soil to which it may be applied and does not develop weeds. It requires about a week or more for the sludge to drain so that it is spadable, depending upon the weather. Freezing interferes somewhat with sludge drying. Mr. Allen's book, page 179, records the dry sludge, free of gas, as having a specific gravity of 1.09 to 1.22.

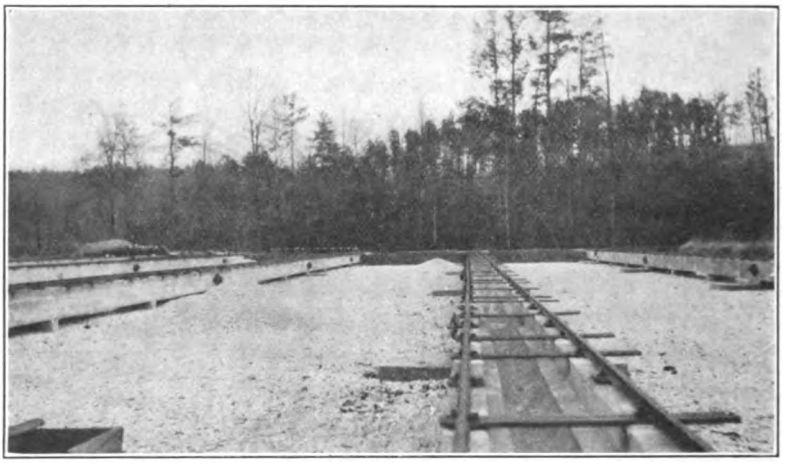


FIG. 42.—Sludge-drying bed, Atlanta, Ga.

On page 228 of Mr. Allen's book it is stated from German data that the volume of sludge as removed from Imhoff tanks is about 16 per cent. of the volume at 95 per cent. water. Circulars issued by the American representatives of Dr. Imhoff give the quantity of sludge as removed at 1200 cubic feet per year per thousand population for separate sewers with strictly domestic sewage. This figure is equal to about 3.25 cubic feet per thousand population daily, and as a result of drying this volume is reduced about 40 per cent., or to about 2 cubic feet. For combined sewers these volumes of sludge should be increased by 50 to 100 per cent. and possibly more. It depends upon the influence of trade

wastes and the proportion of street washings that are diverted from the tanks through storm overflows.

Effluent of Sludge Bed.—This has been studied at length by Messrs. Spillner and Blunk of the Emscher district, as stated in Mr. Allen's book, page 57. It is found to be non-putrescible and free from objectionable bacteria, so that it may be discharged directly into a stream.

OPERATING PROGRAM

As yet there has been almost no experience in this country with the operation of Imhoff tanks in practice. There has been experience at Philadelphia and Chicago showing general confirmation as to the behavior of the process. The best account of practical operations is given by Mr. Saville in his Boston paper above-mentioned and from which the following quotation is taken:

> The actions taking place in the sludge-decomposing chamber of one of these tanks have already been described in detail in the *Engineering Record* of December 10, 1910. As soon as the tank is placed in operation sludge particles begin to enter the decomposing chamber through the slots. This process is continuous and automatic unless the flow of sewage through the tank is interrupted. The sludge accumulates on the bottom of the decomposing chamber, where, as a result of the decomposition of the organic matter, gas is formed in considerable quantities. Numerous analyses have shown the gases to consist almost entirely of marsh gas (CH_4) and carbon dioxide (CO_2), both of which are practically inodorous. The rising gases exert a stirring action on the sludge which is favorable to rapid and complete decomposition of the putrescible organic matter. Most of them escape into the air; but as a result of the head of water on the sludge many fine bubbles remain imprisoned in it.
>
> No sludge is removed until its surface has risen to a point 18 to 20 inches below the slots, the exact position of the surface being determined at intervals of 10 days by means of a flat, weighted board lowered through the openings on the end of a string. The time required for the sludge chamber to fill up in this way depends: (1) on the amount of sludge entering through the slots, (2) on the quantity of non-putrescible substance in the sludge, (3) on the rapidity and completeness of the decomposition of the organic matter, and (4) on the size of the chamber. It is spoken of as the "ripening time" because during this period the biological organisms, which play so important a part in the sludge

decomposition, are developing and helping to produce the environment most suited to their activities. The decomposition of the sludge is said not to be so rapid or complete during the ripening time as in the second year of operation. With many sewages the time required for complete decomposition of the putrescible organic matter in the sludge is not likely to be much greater than two months. In some of the plants of the Emschergenossenschaft the sludge-decomposing chambers (below the slots) are only large enough so that sludge may accumulate in them during a period of three months before withdrawal; but in the smaller installations where it would be inconvenient to provide for frequent withdrawals the sludge chamber has a storage capacity for twelve to fifteen months.

When the surface of the deposited sludge has risen to the desired point, a small amount is withdrawn from the bottom through the pipe simply by opening the valve at the outlet. It is forced out by the head of water in the tank. After withdrawal the sludge flows in open (or closed) conduits to the sludge-drying beds, or enters a collecting well, from which it is forced through a pipe to the beds by a low set force pump. It is inadvisable to use a suction pump, as the gas bubbles are thereby separated from the sludge. When sludge is being withdrawn from the decomposing chamber some fresh sewage from the sedimentation chamber must of necessity enter through the slots. The amount, however, is comparatively small. The frequency with which sludge is withdrawn from the tanks depends on local conditions and the storage capacity of the decomposing chamber. The intervals between withdrawals may vary from two weeks to six months. Under ordinary circumstances it is better to remove small amounts at frequent intervals, a considerable depth of sludge in the chamber being favorable to decomposition. This is specially important if the portion of the sludge chamber below the slots is not deep. On the other hand, it is sometimes desirable to draw down the sludge level as much as possible at the end of the summer so that it will not be necessary to remove sludge during cold, freezing weather. In no case, however, should all the sludge be withdrawn, because it then becomes necessary for the decomposing chamber to pass once more through the ripening time. Furthermore, the flow of sewage through the sedimentation chamber should not be stopped for long periods because the entrance of fresh sludge into the decomposing chamber is thus interrupted and the processes of decomposition checked. It would also be a mistake to lower the water level in the tank. This relieves the pressure on the deposited sludge and will allow the fine gas bubbles in the decomposed sludge to escape. When the tank is then refilled the sludge becomes packed more firmly together on the bottom. It is not so easy to remove through the pipe nor will it dry so quickly on the sludging-drying beds (as will be explained later).

If it becomes necessary to draw out a large part of the sewage for the purpose of making repairs in the tank most of the thoroughly decomposed sludge on the bottoms should first be withdrawn. The upper layers of the sludge deposit may remain, because when the tank is filled again with sewage and placed in operation gases will be developed as a result of the decomposition of the organic matter.

During withdrawal the sludge should not be allowed to flow out too rapidly through the pipe; because if the well-decomposed sludge on the bottom of the sludge chamber does not move readily toward the outlet the water pressure from above may force some of the fresher overlying sludge down through the lower layers into the pipe. This can best be prevented by throttling the gate at the outlet of the sludge pipe, and by using the perforated water pipe on the bottom of the chamber for loosening the sludge just previous to and during withdrawal. Under certain conditions the sludge pipe may become clogged. Troubles of this sort have been experienced when the decomposed sludge has remained for long periods in the tank, and will be likely to happen if small amounts of tar have become mixed with sand in the sludge chamber. The sludge pipe can usually be freed of the clogging material by turning water under pressure into it either from above or from below through the small pipes provided for this purpose—described under "Design and Construction." After each withdrawal of sludge the sludge pipe must be filled with water (or sewage) from the upper end. If sludge were allowed to remain in the pipe it might become badly clogged. Should the above-mentioned difficulties be experienced where water under pressure is not available, it would always be possible to lower a new pipe into the tank and pump out the sludge.

A few words should now be said about the formation of scum in the upper part of the sludge-decomposing chamber. As a result of the stirring action of the gases developed by the decomposition of the organic matter in the sludge there is always more or less movement in the upper layers of the sludge deposit. If the sludge is particularly sticky or contains much grease and fat the gases will be held fast and masses of the sludge will thereby become so light that they rise to the surface. Much of the sludge which rises in this manner sinks again after the gases have escaped into the atmosphere; but there is usually more or less scum floating on the surface of the sewage in the spaces. This scum has no disagreeable odor and as a rule does not accumulate to any great depth. It is loosened up with a rake once a month so that the heavier matters may sink and the gases rising from the sludge chamber may escape easily into the air. Once a year it can be removed with a shovel, if desired, and allowed to dry out on the sludge-drying beds. The movement of the sludge in the decomposing chamber and the formation of scum is usually most noticeable during the ripening time. It

may be controlled to a considerable extent by loosening up the sludge on the bottom at regular intervals of ten days or so by turning water into it under pressure through the small pipes for a few minutes. This allows some of the gas to escape and tends to prevent large masses of sludge from floating. The scum which may form if the sludge contains much grease or fat is likely to be particularly light and foamy. It might overflow, on occasion, into the sedimentation chamber unless drawn off through the outlet on to the sludge-drying beds or unless the walls surrounding the spaces are extended upward for some distance above the level of the sewage in the tank. Such conditions may occur once or twice a year and last for a few days, but they can usually be prevented entirely by loosening up the deposited sludge at intervals as already described. Fats and grease in the sludge do not seem to have an unfavorable effect on the rapidity or completeness of the decomposition.

The sludge when drawn out of the tank is similar in some respects to sludge that has been for long periods in ordinary septic tanks. After remaining the necessary time in the decomposing chamber it has changed materially from its original condition. It is a black, semi-liquid, uniform, porous mass having a slight odor of tar or burnt rubber. It is oily in appearance like the soil sometimes found in low swampy land. About one-third of the organic matter originally present in the sludge has been converted into gas, the remainder being non-putrescible. The sludge contains on an average only 75 per cent. water, and therefore occupies much less space than when first deposited (in its fresh condition) in the tank. As a result, however, of its gas content and the destruction by decomposition of the fibrous material, it flows easily in channels having a slope of 1:40. Its temperature varies between 55° and 63° F., and does not decrease noticeably in cold weather.

The sludge is dried on well underdrained open beds containing 10 to 12 inches of graded slag. The necessary drying time is short, averaging six days in the Emscher district, where there are many rainy days at all seasons. In dry weather it will be spadable at the end of three days. The gas content of the sludge has much to do with the rapidity of drying. When in the tank under 25 to 30 feet of water pressure the small gas bubbles held fast in the sludge become compressed. Part of them may also go into solution. But as soon as the sludge is drawn out on to the drying beds this pressure is removed. The gases expand, making the sludge porous and light enough to float on the water, which settles out beneath and passes quickly down through the slag into the drains. The gases escape into the air, however, and if the beds are not well drained, the water will rise to the top as the sludge settles again, and a much longer drying period will be found necessary. To prevent clogging of the cinders with sludge particles a layer of fine sand (removed

from the grit chambers) is spread on the surface of the beds before each application of sludge. If the weather is very cold or if there is a heavy rain during the first twenty-four hours of drying, the expansion of the gases (which makes the sludge porous) is interfered with and the drying may take longer than would ordinarily be the case. The volume of the sludge is reduced about 40 per cent. during drying, its water content then being 55 to 60 per cent.; the dried sludge is less than 10 per cent. of the volume of the fresh sludge as originally deposited in the tank, and in the Emscher district amounts to about 0.8 cubic foot per year per person connected with the tanks. As a result of the small volume of the sludge and the rapidity with which it dries, the drying beds may be very small. One square foot of area is ordinarily provided for every three persons, and it has been found that one man (the caretaker of the disposal works) can handle the sludge from 30,000 people if the point of deposit is in the immediate vicinity of the plant. Six cubic meters of sludge have been dried on one square meter of sludge-drying bed in a year. The water which drains out of the sludge on the beds is sometimes turbid, but otherwise unobjectionable and entirely free from odor. It contains only small amounts of nitrogenous organic matter, is high in nitrates and non-putrescible.

At most of the plants operated by the Emschergenossenschaft the sludge is used for filling in low areas, being shoveled from the drying beds into small cars on rails and pushed by hand to the dump. It should not be removed from the beds till thoroughly dried. Otherwise it may remain soft (though unobjectionable) for long periods. The dried sludge is firm, porous and free from disagreeable odor even during warm, muggy weather. It looks much like garden loam, can be piled in deep layers and supports vegetation. The sludge when removed from the drying beds is so unobjectionable that the wives of the peasants who buy it for fertilizer help to load the wagons.

RESULTS OF OPERATION

Reference to Mr. Allen's book is made for detailed experience supplementary to the above. The essentials are here summarized.

Available evidence indicates that the Imhoff tank properly built and operated will clarify up to the limits to which plain sedimentation may advantageously be carried. Especially is it to be pointed out that the automatic removal of the deposit by its gravity flow through the slot into the lower compartment, minimizes the effect of scouring velocities, and there is noted in the effluent practically no gas-lifted particles of sludge.

Scum and fatty accumulations upon the walls and sloping

partitions should be removed carefully. Otherwise the decomposition of these substances is to be reckoned with and the effluent may contain to a bothersome extent suspended matters from the scum and detachments from the walls of the upper compartment.

Bacterially this process is equivalent to plain sedimentation at its best. That is, it is not affected by the intensive growths of bacteria in the lower compartment, although the correctness of this statement depends upon the success with which the contents of the lower chamber are prevented from entering the upper compartment.

The stability of the sewage as a result of this clarification is probably improved to the extent of about 25 to 30 per cent. This figure naturally will vary with different sewages with varying proportions of unstable products.

Dissolved oxygen in the sewage would be reduced far less by flowing through these small sedimentation compartments than through large one-story tanks in which septicization is taking place. No dissolved oxygen is present in the sludge from the digestion chamber.

The main feature of this tank is the sludge treatment which causes the putrescible organic matter to become liquefied and gasified in the digestion chamber without offensive odors, and allows a product to be obtained which can be economically treated and finally returned to land as practically humus matter.

THE ODOR QUESTION

The preponderance of evidence from experimental plants at Philadelphia and Chicago, as well as the observations as to operations on a practical scale in the Emscher District, indicate that freedom from odor is one of the marked advantages of this treatment. This does not mean, however, that plants will take care of themselves and not give odor if neglected or carelessly operated. Particularly when the plants are first placed in operation is it necessary to give them careful attention while the contents of the digestion chamber are undergoing the so-called ripening process.

The reason why tanks of the Imhoff type minimize the production of odors is not understood in all of its details. Much valuable discussion, however, is to be found from various contrib-

utors in the paper of Mr. Saville above-mentioned. The first feature is that, as pointed out by Mr. Eddy, the main bulk of the unstable products in the untreated sewage pass out in the effluent and do not become associated in any appreciable way with septicization in a tank which has passed through the ripening stage. Dr. Spillner, an associate of Dr. Imhoff, throws further light upon this by pointing out that much of the organic sulphur content of sewage does not subside, but is to be found in the dissolved and colloidal matters which pass out in the effluent of the sedimentation compartment.

Some have claimed that sulphureted hydrogen is not produced in the Imhoff tank. This is an error when precisely considered, although as a superficial observation it probably records the results noted. If it was said that sulphureted hydrogen which is released from septicization in the digestion chamber meets conditions for its absorption or for its combination with iron or other salts, so that it does not appear at the surface, it would probably indicate more correctly what normally takes place in this type of tank. This general question is touched upon in Chapter III and we will not attempt to elaborate further the data now at hand from the Imhoff tank.

While numerous tanks in the Emscher district show freedom from odor under normal conditions, it appears that there are, as is invariably the case, some exceptions to the rule. Mr. Saville in the quotation above given speaks of the most probable source, namely, when the tanks are first placed in service, or when for any reason the sludge compartment is emptied to an unusual extent after the ripening becomes fully established. If the digestion chamber were first filled with water or stable effluent, and so refilled whenever the tank is partially emptied it will eliminate earlier difficulties.

Undoubtedly different sewages behave somewhat differently, and it has been suggested that perhaps the iron content of sewage in the Emscher district has a favorable effect through ability to produce a black precipitate of ferrous iron in combination with hydrogen sulphide. Dr. Imhoff and his staff state that this is not so. However, the use of proper chemicals such as salts of iron if needed offers a field worthy of most careful study. In particular should it be of much help in guarding against hydrogen sulphide odors during the establishment of the ripening process within the digestion chamber. Such chemicals would precipitate

the organic matters at the bottom of the tank as well as provide means for combination with offensive gases.

E. BOSTON BIOLYTIC TANK

In July, 1909, a tank was placed in service at the new sewage experiment station of the Massachusetts Institute of Technology at Old Harbor Point near the pumping station of the South Metropolitan Sewerage District of Boston, Mass. This tank is described by Profs. Winslow and Phelps on page 280 of the *Journal of Infectious Diseases*, Vol. VIII, No. 3, April, 1911. The tank itself is stated to be square at the top, 7 feet across, with

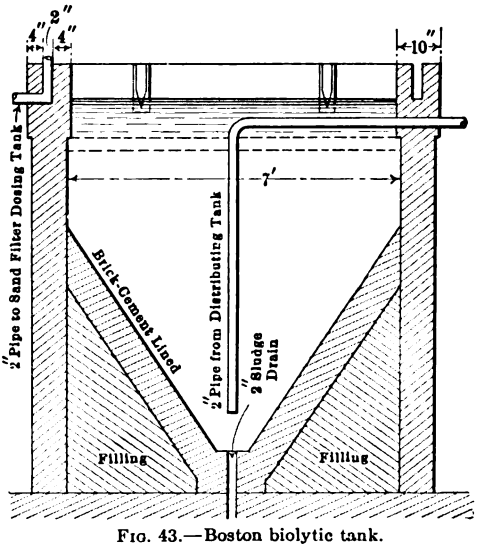


FIG. 43.—Boston biolytic tank.

vertical sides extending downward for a distance of 2.5 feet. Below this the walls converge to a hopper bottom with a slope of 55 degrees from the horizontal. The capacity of the tank, which is shown in Fig. 43, taken from the paper above mentioned, is 1540 gallons. The period of flow is nominally 8.5 hours. This tank receives its sewage through a 2-inch pipe extending to about 9 inches from the bottom of the sewer and the effluent is skimmed from the surface by four triangular metal weirs placed at the corners and discharging into channels in the side walls. These metal weirs are protected by scum boards.

This tank has attracted a great deal of attention as a means of

demonstrating whether or not two-story tanks have certain weaknesses liable to appear as a result of digestion processes being interrupted by the products of bacterial life. This criticism of the two-story tank with the sludge digestion chamber beneath, has been clearly stated by Prof. Winslow in his discussion of the paper of Mr. Gregory on the Sewage Works of Columbus, Ohio. The following paragraph is taken from page 330 of the *Transactions of the American Society of Civil Engineers*, Vol. LXVII, 1910:

> There are two main lines along which the solution of this problem may perhaps be sought profitably. The first is the perfection of the septic tank, or some other form of biolytic chamber, so that a larger proportion of the sedimented solids may be eliminated by microbic digestion. The writer has become convinced that the principal factor which prevents more complete solution of suspended solids is the over-septic condition of the sludge due to the accumulation of waste products of bacterial life. If this be the case, tanks built like the Hampton and Emscher tanks, in such a fashion as to separate the sludge from the flowing sewage, keeping the sewage fresh and the sludge as stagnant as possible, are designed on a diametrically wrong principle, as far as the sludge solution is concerned. At the new experiment station of the Massachusetts Institute of Technology the reverse principle has been applied. A septic tank has been constructed on the Dortmund pattern, the influent entering near the bottom and being skimmed off at the top, so that the sludge is constantly washed and kept from an over-septic condition by the incoming sewage. No data as to sludge digestion are as yet available, for the tank, thus far, has been operated (8 months) without the necessity for cleaning; but the effluent is of excellent character.

This biolytic tank has been in continual use for six days per week and for seven days during the colder months of the year. Samples have been taken and analyzed with unusual thoroughness. The suspended matter was reduced from 163 to 81 parts per million, a reduction of about 50 per cent. As already stated in Table 74, it was found that this tank was quite successful in the digestion of the deposited solids. In fact, of the total solids, the liquefying efficiency is given as 72 per cent. and when expressed with reference to the organic solids, it is 81 per cent. These data represent the results of ten months' operation, ending June 13, 1910. While the results were favorable they do not show for a tank emptied at that season of the year results which

are strikingly different from those recorded for several of the tanks included in Table 75.

At the Chicago sewage testing station a similar tank has been under observation and in the discussion of Mr. Saville's paper, Mr. Pearse, the engineer in charge, speaks of results quite different from those obtained at Boston. In fact, the establishment of conditions of anaerobic gasification have associated with them an evolution of hydrogen sulphide to a greater extent than in other devices at Chicago. It emphasizes a feature which strikingly comes to the front throughout this whole chapter, namely, that different sewages behave differently and it is with great care that the detailed results obtained at one place should be used as a guide to the developments of projects elsewhere.

Taking the evidence as a whole, it may be said that the two-story septic tank is not likely to encounter complications in the matter of arrested sludge digestion, although markedly varying periods may be required for the ripening process to become well established. Digestion chambers should be made amply large and perforated water pipes should be provided where feasible to mix if need be the contents of the digestion chamber. In this way it appears that difficulties are guarded against, such as mentioned by Prof. Winslow in his discussion of Mr. Gregory's Columbus paper. Aid is received also from the reversal of the direction of flow, thus changing the character of the sludge which reaches different portions of the digestion chamber. Natural mixing is obtained by the normal gas ebullition.

It is not likely that the two-story tank, properly operated, will give way to the Dortmund type for the treatment of sludge.

PATENT CONSIDERATIONS

There are two patents which have recently attracted much attention with respect to the septicization of sewage sludge. The first of these is the Cameron patent, No. 634,423, granted in the United States, Oct. 3, 1899, on an application filed Mar. 15, 1897. The other is the Imhoff patent, No. 924,664, issued June 15, 1910.

The Cameron patent, owned by the Cameron Septic Tank Co. of Chicago, has been the basis of considerable litigation, particularly with respect to its infringement by the plant at Saratoga Springs, N. Y. The decree of the United States Circuit Court of the Northern District of New York dismissed this bill for

infringement, declaring both process and apparatus claims to be invalid. The decision is set forth in part in the *Engineering Record* of Mar. 30, 1907.

Appeal was taken to the United States Circuit Court of Appeals of the Second Circuit and early in 1908 a decision was handed down reversing the decision of the trial court as to the process claims, but affirming the findings as to invalidity of the apparatus claims. The opinion in full is to be found in 151 *Federal Reporter* 242, a copy of which appears in the *Engineering Record* of Jan. 25, 1908.

As set forth in Mr. Metcalf's discussion of the antecedents of the septic tank, earlier arrangements unquestionably took advantage, intentionally or otherwise, of anaerobic decomposition. As to these prior uses the Court of Appeals speaks of the intended use of anaerobes as a distinctive part of a process of sewage treatment. The paragraph may be quoted as follows:

> The question of anticipation is greatly simplified by a clear understanding of precisely what the Cameron process is. The crux of the question is stated in complainant's brief as follows: "In all processes of the prior art the aerobic or oxidizing action was continuous from the time the matter left the house as house-waste until the end of its purification as sewage. Cameron's separate anaerobic colony was the first break that was ever made in such aerobic action." It is not disputed that anaerobic action was present to a greater or less extent in prior processes, but it is contended that Cameron was absolutely the first to instruct the art that the problem of removing sludge could be practically eliminated (irrespective of securing other advantages) by providing the anaerobes with a workshop in which they might act upon the solid contents of the flowing current, unhampered by the presence of air, oxygen, agitation or aerobes. With the question so closely limited the burden of comparing prior patents and publications with the Cameron process is materially reduced.

The position was also taken that in earlier arrangements oxygen was present at the outlet, whereas it was stated to be absent in the effluent of the Saratoga tanks. The Court speaks of the process as involving "the use of one of the agencies of Nature for a practical purpose."

Associations for Defense of Suits.—Following the Saratoga decision, associations of municipalities and engineers were formed as already stated in several parts of the country and a determined effort made to resist the payment of license fees until further

light might be obtained on the interpretation of this patent. An unsuccessful effort was made to have the United States Supreme Court review the matter on a writ of certiorari. Some reliance was placed on the failure of the Cameron company to market its English patents abroad, although this is explained apparently by the fact that Mr. Cameron of Exeter secured in England only an *apparatus* patent, whereas in the United States the patent of himself and associates was very broad, covering *process* as well as *apparatus* claims.

Life of Cameron Patent.—The associations above mentioned made active resistance on the belief that the Cameron patent expired following the termination of the 14-year life of British patents following the issue in England in November, 1895. This was the interpretation of the active counsel for both the prosecution and the defense in the Saratoga litigation. Since 1909 this interpretation by some legal advisers has been modified in accordance with the significance of the Brussels treaty of 1902, the purpose of which is to give in the United States to patents of foreign origin the same life as patents of domestic origin. The question at issue is whether the form of adoption of that treaty by the United States made it retroactive or not. In the Hennebique patent case the decision was such as to lead the Cameron company to construe the life of their patent as continuing for 17 years, or for the life of the United States patents following the issue in this country. This would give to the Cameron company's patent a continuance of life until Oct. 3, 1916.

Knoxville, Iowa Case.—This case against the city of Knoxville, Iowa, is pending on appeal in the United States Supreme Court, and if that court sustains the Cameron Company's contention as to the effect of the Treaty of Brussels, it will be a final adjudication that the Cameron patent does not expire until October, 1916. It is expected the case will be decided in 1912. But if the decision is in favor of Knoxville, the Cameron Co. takes the position that only one defendant, Knoxville, Iowa, would be benefited, because it was stipulated by counsel that Knoxville's contention of identity between the British and United States patents might be taken as true, merely to expedite an appeal to the Supreme Court on the Treaty question. In other cases the Cameron Company state they would insist that the expired British patent was not for the same subject matter, and so could not shorten the term of the process claims, and at least some of the apparatus claims, of the United States patent.

Cameron Process Patent Differs from English Patent.—In a pamphlet issued in June, 1911, the Cameron Company sets forth the statement that the English patent was for certain apparatus claims alone and therefore the process claims, and at least some of the apparatus claims, in the American patent are not concerned at all with the provisions of the Brussels treaty, but have the full life of 17 years from the date of issue, or from 1899, in the United States. The Cameron Company refers to certain rulings of the Supreme Court as sustaining the point of law involved in this contention which would leave the above-mentioned Cameron claims in force for the full 17 years of the patent grant, irrespective of the Treaty question above-mentioned.

Current Litigation.—At this time so far as known there are no cases being actively litigated other than the Knoxville case, among municipalities. However, the Cameron company has recently pressed its claims before the United States Government for license fees due to the alleged use of its patent in connection with several institutional plants, among them one at Johnson City, Tenn., where there is a large National Soldier's Home. Testimony was recently taken in these suits before the United States Court of Claims and it is stated that during 1912 it is expected there will be a report to Congress as to the findings on these claims.

Relation of Cameron Patent to Two-story Septic Tanks.—In *Municipal Engineering* of January, 1911, page 5, it is intimated with reference to the Imhoff tanks at Atlanta, that the Cameron Company considers that they will infringe its patent. This it evidently construes to be the basic process patent covering the intensive growth of anaerobic bacteria to promote sludge digestion. As the Atlanta tanks are not now in service, no further developments have arisen with respect to infringement of the five claims decided in the Saratoga case to be valid, as follows:

1. The process of purifying sewage which consists in subjecting the sewage under exclusion of air, of light and of agitation to the action of anaerobic bacteria until the whole mass of solid organic matter contained therein becomes liquefied, and then subjecting the liquid effluent to air and light.

2. The process of liquefying the solid matter contained in sewage, which consists in secluding a pool of sewage having a non-disturbing inflow and outflow, from light, air and agitation until a mass of microorganisms has been developed of a character and quantity sufficient to

liquefy the solid matter of the flowing sewage, the inflow serving to sustain the microorganisms, and then subjecting said pool under exclusion of light and air and under a non-disturbing inflow and outflow to liquefying action of the so-cultivated microorganisms until the solid organic matter contained in the flowing sewage is dissolved.

3. The process of liquefying the solid matter contained in sewage, which consists in secluding a pool of sewage having a non-disturbing inflow and outflow, from light, air and agitation until a mass of microorganisms has been developed of a character and quantity sufficient to liquefy the solid matter of the flowing sewage, the inflow serving to sustain the microorganisms, then subjecting said pool under a non-disturbing inflow and outflow and under exclusion of light and air to the liquefying action of the so-cultivated microorganisms until the solid organic matter contained in the flowing sewage is dissolved and then subjecting the liquid outflow to an aerating operation.

4. The process of liquefying the solid matter contained in sewage, which consists in secluding a pool of sewage having a non-disturbing inflow and outflow from light, air and agitation until a mass of microorganisms has been developed of a character and quantity sufficient to liquefy the solid matter of the flowing sewage, the inflow serving to sustain the microorganisms, then subjecting said pool under a non-disturbing inflow and outflow and under exclusion of light and air to the liquefying action of the so-cultivated microorganisms until the solid organic matter contained in the flowing sewage is dissolved, then subjecting the liquid outflow to an aerating operation, and then to a filtering operation.

21. The process of liquefying the solid matter contained in sewage which consists in secluding a pool of sewage having a non-disturbing inflow and outflow from light, air and agitation until a thick scum is formed on the surface thereof and a mass of microorganisms has been developed of a character and quantity sufficient to liquefy the solid matter of the flowing sewage, the inflow serving to sustain the microorganisms, and then subjecting said pool under the cover of said scum and under a non-disturbing inflow and outflow to the liquefying action of the so-cultivated microorganisms until all the solid matter contained in the flowing sewage is dissolved.

Imhoff Claims.—The claims of the Imhoff patent are two in number, as follows:

1. In sewage treatment apparatus the combination of a depositing chamber having a mud outlet at the base thereof, a mud decomposing chamber below the depositing chamber adapted to receive the deposited mud, means for preventing the return of gases and rising particles from the decomposing chamber to the depositing chamber and means

for providing a flow of liquid through the depositing chamber without disturbing the quiescence of the decomposing chamber.

2. In sewage treatment apparatus the combination of a depositing chamber the sides of which converge to a mud outlet at the base thereof and one of said sides being prolonged to extend past the vertical plane through the edge of the other of said sides, a decomposing chamber below the depositing chamber, said decomposing chamber extending upward above the level of the said mud outlet and means for providing a flow of liquid through the depositing chamber without disturbing the quiescence of the decomposing chamber.

Imhoff License Fees.—These fees have been placed for the present at approximately $50 per thousand population to be connected with the sewers making use of two-story tanks of the type in question. For larger plants the fees diminish somewhat by a sliding scale. So far as known there has not been opposition to the payment of this fee.

General Attitude of Engineers.—While engineers seem disposed on the whole to recommend the payment of license fees for the Imhoff patent, they have opposed vigorously the payments of fees for the Cameron license. In part this is probably explained by the statement made by numerous of the older engineers that in their opinion the Cameron patent related to arrangements known to the prior art and were therefore not valid in their judgment. In part it is explained by the amount of the fee and in part by the fact that the Cameron Septic Tank Company started their efforts with an engineering corps and proposed to design and supervise the construction of tanks as well as to arrange for royalties or license fees covering the patent.

On the other hand, the reception of the Imhoff apparatus patent has been more cordial than in the case of any other patent that the writer knows of in connection with the field of sanitary engineering. The policy pursued by Dr. Imhoff is one in which advantage has been taken by him of the difficulties encountered by the Cameron company.

It is difficult to say what may be the outcome of the patent considerations in the event that the Cameron patent covers the fundamental basic use of intensive anaerobic decomposition.

Judging from experiences in the field of water purification, the situation is a trying one from various viewpoints. With water filters, owners of various patents have been prolific in their criticism of the work of engineers and other patent owners and

have done more or less harm to the advancement of that branch of sanitary work. Several patents are in existence covering the same features. Naturally engineers have not been inclined to recommend the payment of royalty or license fee on one patent where there are other patents that are alleged to be infringed by the same arrangement according to other patent owners. With unadjudicated patents it is difficult to forecast validity. This is well exemplified by the fact that various filter companies have not been disposed to accept license fees and guarantee immunity as to infringement by all other patents covering the arrangements in question.

Recently it has been the practice of the author in connection with water filters to specify that the contractor or builder of plants must insure immunity to the city as to patent fees. Whether this may be necessary or helpful in connection with septicization patents is not known, and cannot be discussed in detail in advance of decisions upon suits now pending. Speaking generally, such a course tends to minimize the present unfortunate wholesale criticism of and fault-finding with numerous projects and to place the commercial aspects on a basis similar to that for pumps, meters, and various mechanical devices in common use.

RÉSUMÉ

Single-story septic tanks have been useful in many small installations. They afford clarification when working at their best, to a degree approximating that obtained with plain sedimentation. But they disgorge sludge and scum at times into the effluent, probably to a greater degree than is generally realized.

With large municipal septic tanks of one-story, difficulty has frequently but not always been encountered. This is caused by septicization and sedimentation taking place in the same compartment. This results in deoxygenation of the flowing sewage and a tendency to objectionable smells. Complications also arise from gas ebullition which lifts particles of sludge into the effluent. This latter feature has proved bothersome as a clogging factor in connection with filtration. It may be controlled by fine screens or roughing filters. Possibly it and other difficulties above mentioned may be remedied by larger tanks than are

generally used in this country, thereby securing a longer period of travel with wider separation of influent from effluent.

Two-story tanks of the Imhoff type seem preferable to those of the Travis type on account of the more complete separation of the sedimentation and digestion compartments. This allows the settled effluent to show none of the disadvantages above-mentioned for single-story tanks as regards deoxygenation, objectionable smells and gas-lifted sludge particles in the effluent.

Septicization under proper conditions affords the best general means of treating sewage sludge so as to make it inodorous. In the lower compartment of two-story tanks this can be done uniformly more advantageously than in single-story tanks. The humified sludge freed of putrifying organic matter is particularly in a suitable condition to be freed from water as it leaves these deep tanks on account of its being well commingled with numerous gas bubbles. In this condition it may be dried so that it will be spadable in about a week's time under favorable weather conditions.

The sludge from single-story tanks is much less readily freed of water than that in two-story tanks, generally speaking. Futhermore, it is difficult to clean single-story tanks and obtain sludge which has been completely rotted out. Of necessity it contains more or less of a mixture of suspended matters not completely digested.

During severe winter weather it is scarcely feasible to remove sludge from two-story septic tanks. The sludge digestion compartment, therefore, should have a capacity for this and other reasons equal to an accumulation of at least six months. The amount of sludge removed from two-story tanks after being dried to a water content of 55 to 60 per cent. amounts to about 3 to 8 cubic feet per thousand population daily, depending upon the quality and quantity of suspended matter in the sewage. The effluent of the sludge drying beds is non-putrescible and may be discharged directly into small streams.

The odor attending two-story septic tanks is found in practice to be substantially nil, although when the tanks are first placed in service there is some tendency to objectionable smells. It appears that this may be controlled with the careful use of salts of iron first and by filling the digestion chamber with water.

The cost of two-story tanks, providing a sedimentation

chamber with about a three hours' period of flow and digestion chambers holding about six months' accumulation of sludge, is about double that, generally speaking, of single-story septic tanks having about an 8-hour average period of flow. The costs vary, naturally, under different local conditions. For the work accomplished two-story tanks are distinctly preferable to the single-story tanks and are well worth the additional cost.

The digestion of sludge in separate tanks or compartments offers no substantial advantages for large works as compared with two-story septic tanks. Neither are substantial advantages to be found in a biolytic tank as tested at Boston and Chicago.

CHAPTER XV

CHEMICAL PRECIPITATION IN CONJUNCTION WITH SEDIMENTATION

Chemical precipitation consists of the addition to sewage before its entrance into settling basins of certain chemicals capable of producing a gelatinous precipitate which envelops many sewage matters that do not subside by plain sedimentation. By this treatment the sewage is clarified and freed of impurities to a greater extent than by plain sedimentation.

This method originated more than 50 years ago in England in an effort to separate from sewage those constituents of value for fertilizing purposes, and with the hope of employing the method on a commercial scale with profit. Commercially this method was early found to be unsuccessful, but in the days prior to bacteriology and the germ theory of disease it did provide a method of treatment which met with much favor for many years. In fact, where sewage farms were not considered practicable this method of chemical precipitation was almost the only process of sewage treatment that obtained a foothold prior to the modern biological processes. Between 1880 and 1890 this method was at the height of its fame, stimulated in part by the investigations of Royal commissions and the recommendation of this process for adoption by the Metropolitan District of London. It is stated that in England alone more than 200 plants of this type were installed. Following the example of London and other large English cities this method was also adopted at a number of places on the continent of Europe and in America.

The early history of this method in America is well set forth by Messrs. Rafter and Baker in their book on "Sewage Disposal in the United States." Of particular interest and value are the reports made by various leading engineers on the development of sewage disposal projects for the cities of Providence, R. I., and Worcester, Mass.

PROVIDENCE PROJECT

In 1884 Mr. Samuel M. Gray, at that time City Engineer of Providence, was directed to investigate European sewage disposal

practice. He inspected the principal works abroad, and in a valuable report made recommendations which were adopted by the city of Providence, as follows:

(1) That a system of intercepting sewers be completed.

(2) That the system of intercepting sewers be so designed as to convey the sewage of the city to Field's Point.

(3) That the sewage be treated at Field's Point by chemicals in such manner as to precipitate the matters in suspension and to clarify the sewage.

(4) That the clarified effluent be emptied into deep water at Field's Point.

My reason for recommending precipitation is that I am confident that the sewage can be so clarified that the effluent will be entirely harmless when emptied into the river at Field's Point, and the purification can be accomplished at less expense than by irrigation. Although sewage is more fully purified by irrigation than by precipitation, I have not felt justified in recommending its adoption, for, from careful and extended surveys, I am convinced that the large amount of suitable land required for irrigation cannot be obtained at any reasonable cost within reasonable distance of the city.

. . . It is proposed to erect pumping works. The sewage from a part of the eighth ward and from most of the ninth will not require pumping. The sewage from the remainder of the city will be lifted about 28 feet into a conduit, through which this sewage, together with that from the eighth and ninth wards already referred to, will flow to the precipitation works.

At this point . . . it is proposed to construct tanks and erect suitable buildings and works for the mixing of chemicals with the sewage, and for the handling of the sludge, etc. The sewage, after receiving the mixture of chemicals, will flow into precipitation tanks, where it will remain for a short time to cause the deposit of sludge; the clarified effluent will flow off into deep water at the point as shown on the plan.

The sludge left in the bottom of the tanks will then pass into receivers, from which it will be forced by compressed air into filter presses.

. . . By these presses the sludge is easily compressed into a portable form. That this sludge possesses some value as a fertilizer there is no doubt; it remains to be proved whether there will be any sale for it in this vicinity. Therefore, for the purposes of this report, I assume that there will be no immediate income from its sale as a fertilizer.

This project, as stated in Chapter X, was reported upon favorably by a commission composed of Messrs. Joseph P. Davis, Rudolph Hering and Robert Moore. Changes incident to the

diversion of the sewage through interceptors to Field's Point required several years for their completion. The plant went into service in April, 1901. It includes 20 tanks having a gross capacity of a little more than 11 million gallons. Four of the tanks are used as roughing tanks, with an average depth of 11.87 feet. The remainder, called finishing tanks, are 8.67 feet deep. Tables 80 and 81 contain results of clarification and of sludge pressing. They also show volumes of sewage treated and other data.

Fig. 44 shows a general view of the plant, furnished through the courtesy of Mr. Otis F. Clapp, City Engineer. A detailed

FIG. 44.—Providence precipitation plant.

description of the plant will be found in the *Engineering Record* of May 4, 1901.

WORCESTER PROJECT

Mr. Charles A. Allen, then City Engineer of Worcester, Mass., also visited Europe and secured the opinions of a number of leading English engineers in the matter of sewage disposal for this American city. This manufacturing city, located on the upper portion of the comparatively small watershed of the Blackstone river, was in frequent difficulty with the State authorities and in court proceedings instituted by riparian owners in the lower towns of the valley. Messrs. Rafter and Baker detail many valuable developments at Worcester in their chapters upon chemical precipitation. In 1889 the City Council authorized the construction of chemical precipitation works, in accordance with Mr. Allen's report of 1887, of which the summary is as follows:

1. That the effluent obtained will without doubt conform to the requirements of the law.

2. That the cost of establishing a plant will be less than by either irrigation or downward intermittent filtration.

3. That chemical precipitation will not be affected by climatic conditions.

4. There will be no loss of water, and consequently no water damages to pay.

5. If this method of disposal is adopted by the city of Worcester, it will be in a position to take advantage, without material change in plant, of improvements that will undoubtedly be made in the methods of sewage disposal.

6. That precipitation will be a valuable auxiliary to irrigation or intermittent filtration, if it should ever be thought desirable to add either of these methods of disposal to the system.

The precipitation works at Worcester were first placed in service in June, 1890. The plant included six tanks 100 feet long, 66.7 feet wide and 5 feet deep. The work is described in detail in *Engineering News* of Nov. 15 and 22, 1890. At first only about 3 million gallons of sewage were treated daily. This flow was increased to 6 million gallons, which were found to overtax the capacity of the plant. It was decided in 1892 to enlarge the plant. In July, 1893, operations were commenced with the enlarged plant, which contains 16 tanks, each of the 10 new tanks being of the same capacity as, although of different dimensions from, the original tanks.

The enlarged plant caused a noticeable improvement in the Blackstone river below Worcester, but it was not long before complaints from the towns below became frequent and insistent. It resulted in extensive litigation, which caused systematic attention to be given to filtration and other means of treatment to supplement chemical precipitation. Reference will be made to this later in this chapter, after noting the results accomplished at the Worcester plant.

Experience in treating the suspended matter at the Worcester plant is well reviewed by Messrs. Eddy and Fales in the *Journal of the Association of Engineering Societies*, Vol. XXXVII, 1906, page 67.

OTHER PROJECTS

In gathering the statistics as to chemical precipitation in 1904 for the International Engineering Congress, the author found that

Providence and Worcester were the only two notable chemical precipitation works in the United States. At that time there were eight in use. The plants at East Orange, N. J., and at Mystic Valley, Mass., had already been abandoned. Several of the plants were proprietary modifications of this method, built after the Powers patents at Coney Island and a number of other places on the outskirts of New York City. Since that time the plant at White Plains, N. Y., has been abandoned, and it is understood that steps for superseding the plants at New Rochelle, N. Y., and Canton, Ohio, are under way. This method is used for the treatment of mill wastes in some places, and it is understood still to be in use for some summer resorts, such as at Chatauqua, N. Y. At the latter place it is said that since 1910 the effluent has been treated with a liberal quantity of hypochlorite of lime.

PRINCIPLES OF PROCESS

The fundamental principles of this process of sewage treatment, so far as they relate to efficiency and to the comparative merits and economy of different precipitants, were carefully studied at Lawrence by Mr. Allen Hazen and published in the special report of the Massachusetts State Board of Health, 1890, Part II, pages 737–95. Knowledge upon matters therein considered has not materially changed since their publication, although information has become more definite as to the practical aspects of the deposition of the coagulated matters, and especially with reference to the treatment of the sludge.

This classical recital of the principles of chemical precipitation, as developed at Lawrence, is admirably summarized by Messrs. Clark and Gage in their review of 21 years' work at the Lawrence Experiment Station in the 1908 Report of the Massachusetts State Board of Health, pages 457–59. This summary is essentially a series of quotations from the original report and is given in full with page references to the original article, as follows:

> If sewage is allowed to stand for a few hours, a portion of the organic matter will settle out; but the greater part is either too finely divided to separate in a moderate length of time, or is in solution. By adding certain chemicals to the sewage, an inorganic precipitate is formed, which settles rapidly and carries with it nearly all of the suspended

matter, and also a portion of the dissolved matter. This is chemical precipitation of sewage (page 737). From 25 to 43 per cent. of the soluble organic matter, as shown by the albuminoid ammonia and loss on ignition, was removed by copperas, ferric sulphate or alum. In addition to this, all of the suspended matter was removed (page 786). Of the other substances present, the insoluble inorganic matters are removed almost completely, while the soluble salts, including chlorine and free ammonia, are not affected in the least, excepting that the acid of the precipitant remains in solution, in combination with the alkali of the sewage. A very large proportion of bacteria and of the other organisms is removed. This is all that can be done by chemical precipitation (page 787). It is impossible to obtain effluents by chemical precipitation which will compare in organic purity with those obtained by intermittent filtration through sand (page 790).

It is possible to remove from one-half to two-thirds of the organic matter of sewage by precipitation with a proper amount of an iron or aluminum salt, and it seems probable that, in some cases at least, if the process is carried out with the same care as is required in the purification of sewage by intermittent filtration, a result may be obtained which will effectually prevent a public nuisance (page 791).

Using equal values of the different precipitants, applied under the most favorable conditions for each, upon the same sewage the best results were obtained with ferric sulphate. Nearly as good results were obtained with copperas and lime, while lime or alum alone gave somewhat inferior effluents. When lime is used alone there is always so much left in solution that it is doubtful if its use would be satisfactory except in case of acid sewage (page 790). It is quite possible that the same process would not give equally good results upon all kinds of sewage. Special sewages may require special treatment. For this reason, and also on account of changes in the prices of the several chemicals, it is impossible to say that one precipitant is universally better than another (page 786).

There is a certain definite amount of lime which gives a better result than less, and as good or better results than more. This amount of lime is that which exactly suffices to form normal carbonates with all the carbonic acid of the sewage. It is possible in a few minutes, by a simple titration, to determine approximately the amount of uncombined carbonic acid present in sewage, and how much lime will be required to combine with it. It is also possible to determine in a similar way whether enough or too much lime has been added (page 789). By treating sewage with a large excess of lime the undissolved calcium hydrate, in settling, carried down the insoluble organic matter almost completely, and in a very short time (page 747). The action of smaller amounts of lime is quite different. Calcium carbonate is then formed

with the carbonic acid of the sewage, and it is this carbonate instead of the hydrate which clarifies the sewage. Calcium carbonate is somewhat soluble in sewage containing carbonic acid. To obtain a precipitate it is necessary to add enough lime to combine with the greater part of the carbonic acid. The amount of calcium carbonate precipitated can be computed in three ways: *First, from the alkalinity.* If we add the alkalinity of the sewage to that of the lime used, we obtain the total alkalinity of the mixture. As calcium carbonate precipitates, the alkalinity becomes less, and the decrease multiplied by 50, the equivalent weight of calcium carbonate, gives the amount of the precipitate. *Second, from the solids.* One ton of lime per 1 million gallons is equal to 30 parts per 100,000 of calcium carbonate. If we add the weight of the lime used to the fixed residue of the filtered sewage and deduct the fixed residue of the precipitated sewage, we shall obtain the amount of the precipitate. *Third, from the carbonic acid.* The difference between the acid number[1] with phenolphthalein and the alkalinity represents one-half of the total carbonic acid, and the decrease in carbonic acid represents the calcium carbonate precipitated. These three processes give fairly concordant results, and are quite independent of each other, and the possible sources of error are entirely different (pages 748, 749). The lime process has little to recommend it. Owing to the large amount of lime water required, and the difficulty of accurately adjusting the lime to the sewage, very close supervision would be required to obtain a good result, and even then the result is inferior to that obtained in other ways.

Precipitation with copperas is also somewhat complicated, owing to the necessity of getting the right amount of lime mixed with the sewage before adding the copperas (page 786). Ordinary sewage is not sufficiently alkaline to precipitate copperas, and a small amount of lime must be added to obtain good results. The quantity of lime required depends upon the composition of the sewage and the amount of copperas used, and can be calculated from a titration of the sewage (pages 789, 790). When copperas is added to sewage alone, no precipitation takes place, and the result is no better than when sewage settles alone. The addition of enough lime to combine with the excess of carbonic acid over the amount required to form bicarbonates, and to combine with the sulphuric acid of the copperas, is necessary for precipitation; for, while sewage is alkaline, its alkali is all in the form of bicarbonate, and alkali as normal carbonate or hydrate is required to precipitate the iron. When this amount is added, the acid number with phenolphthalein will be zero. To insure a rapid action, a little more than this should be added. No better result is obtained when

[1] The alkalinity is determined by titrating with twentieth normal sulphuric acid, using methyl orange as indicator; the acid number by a similar titration, using phenolphthalein as an indicator.

more lime is used. If much less is used, the iron will not be precipitated (page 764). If enough or too much lime has been used the mixture will color phenolphthalein red, while if too little has been used no color will be produced. This test affords an easy and accurate method of applying enough lime and of avoiding an excess. Very imperfect results are obtained with too little lime, and the excess is wasted when too much is used. With a suitable amount of lime the more copperas used the better the result; but with more than one-half a ton per million gallons the improvement does not compare with the increased cost (page 790). The amount of iron left in the effluent is much greater than with ferric sulphate, owing to the greater solubility of ferrous hydroxide (page 786).

In precipitation by ferric sulphate and sulphate of alumina the addition of lime is unnecessary, as ordinary sewage contains enough alkali to decompose these salts (page 790). Ferric sulphate and alum have the advantage over both lime and copperas, that their addition in concentrated solution can be accurately controlled, and the success of the operation does not depend upon the accurate adjustment of lime or any chemical to the sewage (page 786). Within reasonable limits the more of these precipitants used the better is the result, but with very large quantities the improvement does not compare with the increased cost (page 790). The results with ferric sulphate have been, on the whole, more satisfactory than those with alum. This seems to be due in part to the greater rapidity with which precipitation takes place, and in part to the greater weight of the precipitate. It is probable from the greater ease with which ferric sulphate is precipitated, that it would give a good result with a sewage that was not sufficiently alkaline to precipitate alum at once (page 786).

The behavior of various chemicals in coagulating turbid water is described at length by the author in his book on "Water Purification at Louisville, Ky.," 1898. Some of the facts are of general interest for sewage work. Different sewages behave differently, particularly as to the effect of various chemicals upon the non-settling solids. Comprehensive descriptions of the application of ferric sulphate and lime to the Glasgow sewage have been recently presented to the Institution of Civil Engineers by Messrs. MacDonald, Taylor and Morton. Ferrous sulphate is oxidized by aeration after mixing the hot solution with a small quantity of nitrate of soda.

EFFICIENCY AND COST

As regards general efficiency, this treatment will ordinarily remove from normal sewage from 50 to 55 per cent. of the total

organic matter, and in the neighborhood of 90 per cent. of the total suspended matter. The bacterial removal is usually about 80 to 90 per cent. The fresher the sewage the higher will be the percentage removal of impurities.

The effluent of chemical precipitation works is ordinarily not stable; that is to say, it putrefies upon standing when unmixed with water containing a considerable proportion of dissolved oxygen. The latter constituent is ordinarily absent from the effluent of chemical precipitation works unless the sewage is very fresh and unless oxygen is added by special aerating devices. Although both the sludge and the effluent of chemical precipitation works will putrefy, it is quite rare for seriously objectionable odors to appear around the plants if they are well managed. This relates especially to the frequency with which the sludge is removed during warm weather. No deodorants are used except at a number of plants in and around New York, built after the Power patents, and where chlorine has been applied at times to the partially settled sewage.

Copperas and lime are the chemicals which seem best adapted, generally speaking, to the economical coagulation of sewage. In some cases municipal sewages contain manufacturing refuse so as to modify this general statement. For instance, at Worcester, Mass., the city sewers receive large quantities of pickling liquor from steel plants, so that the sewage, as it reaches the precipitation works, already contains excessive quantities of sulphate of iron. Lime is highly useful at Worcester, but is considered to be of little benefit at London, according to a recent report of Sir Maurice Fitzmaurice, Chief Engineer of the London County Council.

Sulphate of alumina is well adapted for use as a precipitant but is more expensive than those mentioned, and, according to the experience at the precipitation works of the Columbian Exposition at Chicago, the sludge could be less readily pressed into cakes when it was used as a precipitant than when copperas and lime were used. Perchloride of iron has been used at the several plants around New York built after the Power patents. This precipitant is efficient but expensive.

All basins at the chemical precipitation works in this country, as far as known, are operated on the continuous displacement, and not on the fill and draw, plan. Their nominal capacity

ranges ordinarily from 30 to 70 per cent. of the average daily flow, disregarding the contents occupied by sludge.

Through the kindness of Mr. H. P. Eddy, formerly Superintendent of Sewers at Worcester, Mass., and of Mr. Otis F. Clapp, City Engineer of Providence, R. I., very full data were made available to the author in 1903, showing the leading results of operation at these two principal chemical precipitation works, as given in Table 80:

TABLE 80.—SUMMARY OF PRINCIPAL RESULTS OF OPERATION OF CHEMICAL PRECIPITATION WORKS AT WORCESTER AND PROVIDENCE, 1903

	Worcester	Providence
Population connected to sewers, estimated	122,000	170,000
Average daily sewage flow, total, in millions of gallons	15.55	20.38
Average daily sewage flow treated in millions of gallons	14.39	20.00
Total annual sewage flow treated, in millions of gallons	5,250	7,300
Applied lime: Pounds per million gallons	871	606
Applied lime: Grains per gallon	6.1	4.2
Applied copperas: Pounds per million gallons	0	65
Applied copperas: Grains per gallon	0	0.46
Gross capacity of basins, in millions of gallons	5.5	11.1
Percentage of removal: Total organic matter by albuminoid ammonia	51.69	49.80
Percentage of removal: Suspended organic matter by albuminoid ammonia	91.58	82.54[1]
Wet sludge: Average gallons pressed daily	67,200	95,600
Wet sludge: Percentage of total sewage flow	0.4671	0.4776
Wet sludge: Average percentage of dry solid contents	7.44	5.37
Wet sludge: Average pounds of lime added per one thousand gallons	33.5	23.6
Pressed sludge cake: Tons daily	69	76
Pressed sludge cake: Percentage of dry solids	30.3	28.25
Dry solids in sludge: Tons daily	20.8	21.4
Dry solids in sludge: Tons per million gallons	1.45	1.07
Dry solids in sludge: Tons per 1000 population per annum	62	46
Cost of sludge pressing and disposal: Per ton of dry solids	$3.39	$2.27
Cost of sludge pressing and disposal: Per million gallons sewage flow	4.91	2.44
Cost of chemical precipitation—labor and supplies—per million gallons	4.01	3.31
Total cost of operation: Per million gallons	8.92	5.75
Total cost of operation: Per capita connected to sewers per annum	0.384	0.248
Cost per ton: Lime	6.00	6.90
Cost per ton: Copperas		7.80
Minimum wage per hour for laborers	0.23½	0.15

[1] Providence sewage well screened before treatment.

In comparing these data it is to be borne in mind that at Worcester there is much pickling liquor in the sewage, thus

requiring much lime to be added but no copperas. At Providence the sewage contains considerable waste liquor from dye-works, at certain periods of the day, and this gives the effluent there a somewhat discolored appearance. A fairly clear effluent results from treating by this process ordinary domestic sewage which is fresh and uncomminuted. During the portions of the day when the raw sewage is strongest, copperas was formerly used at the Providence works, but not recently. The smaller percentage of suspended matter removed at Providence, as compared with that at Worcester, is explained partly by the more thorough screening at Providence. In comparing the cost of treatment at the two plants as given above, it is necessary to consider not only the greater repair account for the older plant at Worcester, but also the difference in the raw sewages, and particularly the difference in the local labor markets in 1903. At Providence all ordinary laborers were paid $1.50 for 10 hours; at Worcester the minimum wage was $1.85 for 8 hours, and some were paid more.

Data for the year 1910 differ somewhat from the records tabulated for the year 1903; and, based on the reports of Mr. Clapp, City Engineer of Providence, R. I., and Mr. Matthew G. Gault, Superintendent of Sewers, Worcester, Mass., Table 81 has been prepared.

TABLE 81.—SUMMARY OF PRINCIPAL RESULTS OF OPERATION OF CHEMICAL PRECIPITATION WORKS AT WORCESTER AND PROVIDENCE, 1910

	Worcester	Providence
U. S. Census population, total	145,986	224,326
Estimated population connected with sewers	136,000	199,000
Million gallons average daily sewage flow, total	14.57	15.03
Million gallons average daily sewage chemically treated	9.81	14.65
Pounds of lime used per million gallons	989	485.5
Pounds of other chemicals per million gallons	0	*
Million gallons capacity of settling tanks used	4.3	11.13
Percentage removal of total albuminoid ammonia	34.9	48.32
Percentage removal of suspended ammonia	77.8	82.64
Volume of sludge in percentage of sewage treated	0.445	0.468
Percentage of solids in wet sludge		7.93
Percentage of solids in dry sludge (pressed)		27.6
Tons of pressed cake per million gallons of sewage	3.7	5.6
Cost of chemical treatment per million gallons of sewage	$5.25	$3.11
Cost of sludge disposal per million gallons of sewage	4.53	4.06
Total cost of treatment per million gallons of sewage	9.78	7.17

* 19 tons of bleaching powder used in experiments in disinfection of effluent.

SLUDGE DISPOSAL

Sludge is advantageously removed about once a week from the "roughing tanks" (in which the sewage first enters and the coarser matters are precipitated). The "finishing" tanks, through which the sewage last passes and in which the finer particles are deposited, are cleaned once in three to eight weeks, depending somewhat upon the advantageous management of the sludge disposal plants. It is preferable to clean them at least once a month.

The pressed sludge cake is disposed of with little or no nuisance at Worcester by conveying it by trolley car to vacant land in the general neighborhood (about one mile) of the disposal works. A small portion, about 5000 cubic yards in 1909, is carted away by farmers. This method of dumping on low land would hardly be a permanent method of disposal of the matters removed from the sewage from some localities, as this sludge cake accumulates at the rate of about 4 or 5 cubic yards per million gallons of sewage treated. Ultimately it would become difficult to dispose of such accumulations in this way near some large communities.

At Providence pressed sludge cakes were used for filling low land up to July 8, 1908. Since that date the pressed sludge has been conveyed by a double-bottom scow to the United States Dumping Station in 75 feet of water.

Sludge Pressing.—Fig. 45 shows the arrangement of the presses at Providence and the following notes, taken from the 1910 Annual Report of Mr. Clapp, City Engineer of Providence, show further details. The average daily volume of sludge pumped is 68,679 gallons, of which the dry solids average 7.93 per cent. The sludge is pumped by two Shone ejectors of a capacity of 500 gallons each to storage reservoirs; thence it flows by gravity to forcing receivers, of which there are four, each 8 feet in diameter and 12 feet long; thence it is forced under 60 to 80 pounds pressure per square inch into the presses. There are 18 filter presses, each with from 43 to 54 plates with 6-inch center holes, forming cakes 36 inches square and from 0.75 to 1.25 inches thick between the filter cloths which surround the plates. For each thousand gallons of sludge pressed there is added on an average 47 pounds of lime. The ejectors and forcing receivers are run by air pressure generated by one 150 and one 50 horse-

power air compressor actuated by electric motors. The presses are operated on an average about 5.74 hours daily, and there are produced a daily average of 82.22 tons of sludge cake, equal to 22.69 tons of dry solids. The daily cost for light, heat, and power is $5.94.

Attention is particularly called to the fact that sludge disposal is more expensive at Providence than is the cost of treating the

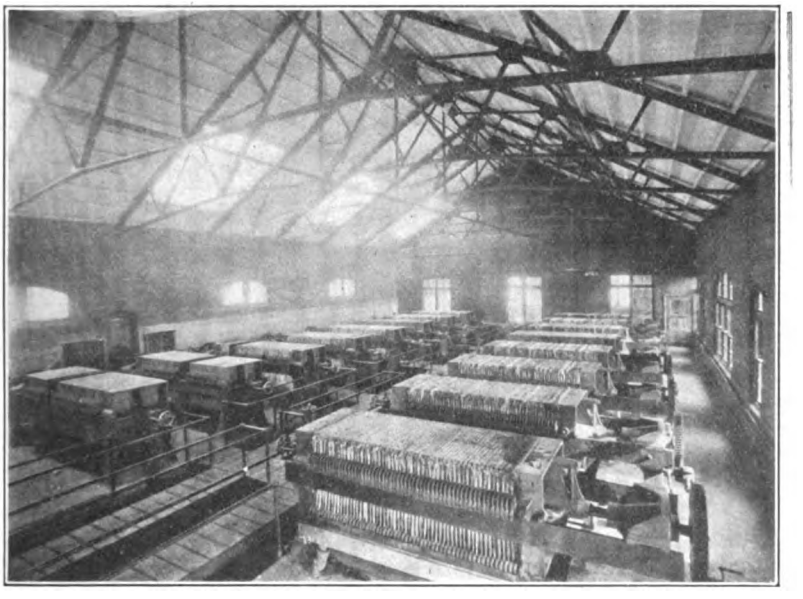


FIG. 45.—Providence sludge presses.

sewage with chemicals. At Worcester the sludge disposal is a little less than the cost of chemical treatment, but this is due to the unusual amount of lime required on account of the iron wastes from steel works.

PRESENT STATUS OF CHEMICAL PRECIPITATION

In recent years practically no chemical precipitation plants have been built in this country, and plants built in former years are being abandoned or used in other ways. The reason is that while coagulating chemicals increase the degree of clarification as compared with plain sedimentation, the increased cost as a preparatory treatment either for dilution or filtration is rarely justified by the result obtained. This is particularly true when

account is taken of the increased volume and cost of sludge which requires treatment.

The final effluent is ordinarily putrescible and consequently the process is not complete in itself for eliminating nuisances under many conditions. It will prevent sludge banks, but this can be done at less cost with plain sedimentation.

As a preparatory treatment for filtration its use has much more merit in the case of sewages highly charged with trade wastes than for ordinary domestic sewage. In some European projects chemical precipitation is still held to, because it is believed that its cost is justified by the increased rate at which the filters may be operated. With our dilute American sewage it is not believed that this will be the case under any ordinary circumstances. Furthermore, the effluent of chemical precipitation plants clog sand filters to a bothersome degree.

Worcester.—At Worcester the plant is operated in response to statute requirements "to remove from its sewage before it is discharged into the Blackstone river the offensive and polluting properties and substances there, so that after it is discharged into said river either directly or through its tributaries it shall not create a nuisance or endanger the public health." The effluent is discharged into the small Blackstone river. For more than ten years this process has been gradually supplemented and superseded by filtration. In 1910 there were treated 3580 million gallons by chemical precipitation; 1722 by plain sedimentation and intermittent sand filtration, the plant for which had at that time an aggregate area of 64.7 acres; and 15 million gallons on the small sprinkling filters operated for experimental purposes.

Providence.—At Providence the effluent is discharged into 36 feet of water beyond Field's Point. As stated in Table 81, experiments were made with the use of bleaching powder for purposes of sterilization. It is understood that good results were obtained with the destruction of over 99 per cent. of the bacteria. The cause of this work upon sterilization is understood to have been the unfavorable influence which the effluent the plant may previously have had upon shellfish layings.

It is stated by Mr. Clapp that during 1911 experiments were made in the use of hypochlorite of lime to disinfect the entire raw sewage which after sterilization was settled without coagulating chemicals. The entire plant was used for sedimentation, and it is stated that good results were obtained.

During recent experience with plain sedimentation as distinguished from chemical precipitation the sludge has been pressed with the aid of a small amount of lime. It is stated by Mr. Clapp that consideration is now being given to carrying the sludge without pressing out to deep water.

It is thus seen that the general tendency of American experiences is toward the abandonment of chemical precipitation, although it is yet too soon to state in its entirety what detailed procedure will be adopted either at Providence or Worcester.

RÉSUMÉ

Chemical precipitation affords efficient clarification, but the removal of finely suspended matters due to coagulation does not permit a stable effluent to be obtained from ordinary city sewage. The effluent is freer of organic matter than that obtained by plain sedimentation, and this allows a smaller degree of dilution when dispersed in water and of a higher rate of filtration, other things being equal. But present evidence shows strongly that the improvement in the quality of the effluent over that obtained by plain sedimentation is not commensurate with the cost involved.

For ordinary sewages the day of chemical precipitation plants is rapidly passing. In the case of certain trade wastes there may be a field of usefulness for this method of clarification. With good management this method of treatment has not given much trouble as to odors, but it has developed complications as to the clogging of fine-grained filters, as will be mentioned in connection with intermittent sand filters.

Comparing it with plain sedimentation in two-story septic tanks, chemical precipitation does not now give promise of being a serious competitor in the treatment of fairly normal sewages.

CHAPTER XVI

ELECTROLYTIC TREATMENT

Electricity for the purification of water or sewage seems to provide wonderful fascination to the lay mind and it is certainly attractive to the scientist. From time to time in various parts of the world in one form or another electricity has been suggested and will no doubt again be suggested as a means of purification on a large scale. In 1890 during a visit to London, England, one of the most interesting features in connection with sewage disposal that came to the attention of the author was the work being done with the Webster process for the treatment of sewage by electrolysis. This process was tested at Crossness, Salford and a number of other places, where it was reported upon by Sir Henry Roscoe and other leading scientists.

The late Santo Crimp, one of the ablest sanitary engineers of his time, was attracted by this process and in the 1894 edition of his excellent book on "Sewage Disposal" devoted the closing chapter to it. He spoke of the correctness of the principle underlying the process, recognized the difficulty in its application, and considered that it was not insurmountable. This chapter, some 11 pages in length, is devoted largely to a description of the process by Mr. Webster himself and from which extracts are reproduced here, as follows:

THE WEBSTER PROCESS

It may be that scientific knowledge is not sufficient at present to entirely and finally deal with this question. We should, however, aim at as high a standard of purification as possible—it is of no use to try half measures—and whatever the treatment may be, the nearer Nature's action is approached, the nearer will be the solution of the difficulty.

Oxidation.—The oxidation of organic matter can only be attained by one mode—chemical action—whether it be by filtration accompanied by the action of micro-organisms, the addition of chemicals, or by mechanical force represented by the electric current.

Effect of Electrolysis.—The chemical changes that take place in

sewage when it is electrolysed depend chiefly on the well-known fact that water as well as sodium, magnesium, and other chlorides (which are always present in sewage), are split up by the electric current into their constituent parts. Thus, we have at the positive pole chlorine and oxygen set free, and these elements are liberated in a nascent state, a condition in which they are intensely active, so that the organic matter in the sewage is rapidly oxidized into innocuous compounds. So rapid is this action that, provided the sewage contains a sufficiency of chlorides, it is possible to produce a disinfecting fluid from it consisting of oxides of chlorine.

The first experiments were made with platinum plates, but the experience was that the cost of platinum put its use out of the question, besides which there was a very slight action on the positive plate, which distinctly pointed to its ultimate destruction. For the treatment of sewage it is absolutely necessary that precipitation of the matters in suspension should take place, and the more complete this is the better the ultimate result. After a long series of experiments in the laboratory, it was found that oxidizable plates produced the desired result. These plates should be of such material that they shall have no poisonous after-effects either on land or in rivers. The metal should be either aluminum or iron; the first-named is out of the question owing to cost, but iron, besides having the advantage as regards price, in the form of oxide has many valuable qualities, one of the chief being that sulphureted hydrogen cannot exist when ferrous or ferric oxides are present. It is well known that oxide of iron, in the hydrated form, is largely used for purifying coal gas from sulphureted hydrogen. After many months of exhaustive experiments, carried out on a large scale at Crossness, it has been conclusively proved that cast-iron plates of the commonest quality, employed as electrodes, give the best result.

Electrical Action.—The electric action is easily explained. At the positive pole the chlorine and oxygen given off combine with the iron to form a salt which is doubtless for the moment a hypochlorite of the metal, but it immediately changes into a chloride, which in its turn is deprived of chlorine to form ferrous carbonates and oxides. During the chemical action carbonate of iron exists in solution, and its formation is due to the presence of carbonates in the sewage, chiefly carbonate of ammonia. In samples that are absolutely free from dissolved oxygen, the ferrous oxide in the white form is precipitated, and on shaking it up with air it changes to the usual pale green color; the carbonate of iron at the same time being oxidized, the ultimate red precipitate is known as ferric oxide, Fe_2O_3, and sometimes this changes, after a time, back again to the ferrous state, FeO, thus showing that it has acted as a carrier of oxygen to the organic matter present. On a small scale the precipitate is carried to the top, due to the bubbles of hydrogen collecting round the

particles of matter in suspension, but it ultimately sinks in the usual manner. In practice the precipitate does not rise, owing to the larger evaporating area, which allows the escape of the gases produced. The current required for the action varies with the nature of the sewage. It is usually assumed that 1.5 volts are required for splitting up water into its component parts; this may possibly be true with carbon plates, but with iron plates acting on sewage the same result can be obtained with 0.9 volt as with double the intensity; of course it takes a longer time, for with such a low voltage the quantity of current is small.

Current Required.—An ordinary sample of sewage requires, on an average, one ampere of current for 10 minutes per gallon, but when mixed with foreign matter, such as manufacturers' waste products, the amount required can only be ascertained by experiment.

Care of Plates.—The plates themselves should always be kept under water, so as to prevent the formation of the red oxide on the surfaces, and the action should be continuous as far as possible, for if continuous the plates seem to acquire some property which reduces the resistance to the electric current, and therefore lessens the cost. At the beginning of a month's run, which lately took place, the voltage measured across certain plates was 3, but after a few days only 1.79, when doing the same work. On examining the plates freshly taken from the liquid they were in, a thin coating of the black or magnetic oxide of iron was found, which has the property of preventing the rusting of the plate under water when the electric current is cut off.

Screening.—The sewage to be treated should, of course, be screened in the usual way and then allowed to run through the plates, so that every molecule shall come into contact with the surfaces of the metal.

Plant.—For 1 million gallons sewage flow in 24 hours, the complete plant necessary is: Engine-, dynamo-, and boiler-house; two engines and boilers, each 12 horse-power nominal; two dynamos; brick chutes with culverts at side; two settling tanks; sludge tanks; sewage culvert; treated sewage culvert; cast-iron plates, copper conductor, measuring instruments.

Electrodes.—By actual experience we have been able to prove that at least 25 sections of electrodes should be in series, and across any one of these sections the potential difference need not be greater than 1.8 volts, the current being of any desired amount, according to the surface of plates used. In experiments lately carried out, a current of 370 amperes was used, which was calculated as .23 ampere per gallon per hour; or, taking it in watts, the estimated horse-power required per million gallons in 24 hours was 26. These figures have been checked by Dr. John Hopkinson. The organic matter in solution of the particular sewage acted on upon this occasion showed a reduction of 61 per cent. after treatment. In other cases a purification of as much as 87 per

cent. has been obtained. If a lesser purification be sufficient, it would mean a reduction of horse-power, as during another run that lately took place, the measurement across the electrodes proved that 19 estimated horse-power was sufficient to treat 1 million gallons in 24 hours, the resulting purification of organic matter in solution amounting to 50 per cent., the waste of the iron plates showing an average of two grains per gallon of sewage treated.

Biology.—The bacteria question is one which has probably still to be settled, but in order to obtain some information as to the action of the iron compound produced by electro-chemical decomposition, some experiments were carried out, with the result that after a given treatment the whole of the bacteria were killed. In the case of experiments carried out in Paris with ordinary treatment by means of iron electrodes, the results were as follows:

	Raw Sewage	Effluent.
Organisms per cubic centimeter,	5,000,000	600

Another experiment in which the effluent was treated still further, so that a slight odor of oxide of chlorine was perceptible, destroyed all organisms, and the liquid remained sterile.

Conclusion.—In conclusion, it is submitted that the application of the electric current in the several ways described produces a precipitating and oxidizing action similar to natural processes, in which the organic matter is destroyed by oxidation due to dissolved oxygen slowly absorbed from the air, assisted in many cases by matters in the soil, such as oxides of iron, acting as carriers of oxygen, and it is also stated that the question of cost will bear favorable comparison with any process which really does the work attributed to it.

SANTA MONICA PLANT

Santa Monica is a residential suburb of Los Angeles, California, located upon the shore of the Pacific ocean. There was installed in 1908 a plant for treating the local sewage in a manner quite closely resembling that of the Webster process. This plant was built mainly on the lines of the Harris Magneto-Electric process, California rights to which were owned by the California Water Purification and Sanitation Company, with such modification in flumes, assembling of electrodes, conduction of current, etc., as the experience of the builders at the Harris demonstration plant at Venice suggested. The test plant at Venice was in another suburb of Los Angeles, adjoining Santa Monica.

The iron and aluminum plates went to pieces in three weeks. All iron plates were substituted which lasted two years. The magnets were soon found to be useless and have since been taken out. The perforated pipes for cleaning the electrodes by steam were found to be utterly worthless for that purpose, even at a pressure of ninety pounds, and were abandoned. Instead a double-throw switch was adopted and the current is reversed once a day. Besides removing accretions this gives uniform wear to the plates. Copper channels, or binding strips, were placed on the upper edges of the iron plates soon after they were put in, which protect the edges from too rapid corrosion and supply copper sulphate in the treatment.

The Santa Monica plant is no longer considered a Harris plant as the Harris features have been eliminated. U. S. patents were obtained by the builders, covering the features of modification, and the business is now carried on by the Electro-Sanitation Company, who furnished the author with the foregoing historical statement of developments at Venice and Santa Monica.

The author visited this plant in April, 1911, and found that treatment is given to the sewage of a permanent population of about 12,000. At certain seasons of the year this population is said to be about double. The sewage is pumped to either or both of two wooden flumes each 30 feet long by 22 inches wide and 18 inches deep. A third flume was added in 1911. In each flume are 10 sets of electrodes spaced 32 inches from center to center and operated in parallel. Each set of electrodes consists of 29 No. 8 gage iron plates, 9 by 24 inches, spaced 0.625 inch apart. The electric current ordinarily has a voltage of from 2 to 4 and an amperage of from 700 to 800.

In *Engineering-Contracting* of April 19, 1911, mention is made of the durability of the iron plates, as described by Mr. H. Hawgood, M. I. C. E. There seems to be an undue tendency to decomposition along the upper edges of these plates which, however, have been protected since August, 1908, by copper clips or bindings. In the article mentioned it is stated that the consumption of iron is indicated to be at the rate of about 20 pounds and of copper in the binding strips at the rate of about 1/3 pound per million gallons of sewage treated.

The electric current is reversed from time to time. The only interruption in the service is for the flushing of the deposits from the electrodes. This is done with the aid of a hose with the

sewage drained from the flumes during the interval that the pumps are stopped for cleaning purposes. Normally it is stated that the sewage stands to a depth of about 15 inches in the flumes, or about 2 inches above the tops of the electrodes.

The sewage passes from these electrolytic devices to an outfall pipe attached to the concrete piles of the municipal pier. The outlet discharges downward about 10 feet below mean tide level at a distance of about 1600 feet from shore at high tide.

City Engineer Thomas H. James states that the plant treated in 1910 about 550,000 gallons per 24 hours. The cost of maintenance is given at $400 per month. This covers the salary of two operators at $85 per month each, who attend to police duties and other work, and also the electric current for which a charge is made of 3 cents per kilowatt hour. This current is used both for the pumping and electrolytic plants. The latter is about 22 feet above mean tide level. Mr. James also estimates that, exclusive of pumping, it would cost about $5000 per annum to dispose of the sewage of a city of 75,000 population, based on local experiences. The Santa Monica plant cost $18,000, including pumping equipment.

Information is meager as to what is regularly accomplished as to purification at the Santa Monica plant. Prof. Salathé shows some comparative analyses in which the raw sewage in parts per 100,000 contains 2.09 parts of organic matter and 27.7 parts of chlorine. These constituents in the samples of treated sewage were 1.26 and 11.03 parts, respectively.

Mr. Willis T. Knowlton, Engineer-in-Charge of Sewers at Los Angeles, speaks of a number of tests which he made of this device. The results are reported in the publications of the Engineers and Architects Association of Southern California. His paper also appears in the *Southwestern Contractor and Manufacturer* of Jan. 15, 1910. These tests as reported by Mr. Knowlton indicate merely a nominal removal of albuminoid ammonia and oxygen consumed from sewage by treatment in the Santa Monica plant. The analyses, made in coöperation with Prof. L. J. Stabler, Professor of Chemistry of the University of Southern California, were nine in number and were made on different days in June, 1909.

On the author's visit to Santa Monica he was informed by Mr. James, City Engineer, that the process gave no trouble whatever as to objectionable odors. This is confirmed by other

city officials and citizens. In fact, there is no local evidence of dissatisfaction. The plant is located in a concrete compartment beneath the street near the shore, close to the entrance to the public pier. It does not seem likely that there have been nuisances at Santa Monica. The real question at issue is whether or not the plant accomplishes any substantial purification, and whether the treatment is as effective and cheap as would be the case with screens or sedimentation, or both.

This method has received some attention quite recently at Atlanta, Ga., Pasadena, Cal., and elsewhere. It has also been adopted at Oklahoma City.

OKLAHOMA CITY PLANT

At Oklahoma City, Okla., a plant similar to the one at Santa Monica, Cal., has been installed according to an article by Mr. C. L. Edholm in the *Municipal Journal and Engineer* of Feb. 8, 1912. The capacity of the plant is given as 750,000 gallons per 24 hours with an installation cost of $12,000. It is stated that the cost of electric current is about $700 per annum, which with one attendant and fixed charges on the investment of about 5 per cent., makes a total cost per annum of $2509.50. This is equal to a total cost of $9.17 per million gallons.

Mr. Edholm states that the Oklahoma plant underwent a six months' trial test and that a second plant has since been ordered. Data are meager at Oklahoma City as to what the plant accomplishes. The electrolytic process is spoken of in connection with the deodorization of sewage and the destruction of the disease germs therein. It is stated that tests by the City Bacteriologist, Dr. C. E. Lee of Oklahoma City, indicate a removal of from 98 to 99.82 per cent. of the bacteria in sewage. Mention is also made by Dr. Lee that the number of ordinary algæ after the liquid leaves the plant seems to increase rapidly. The outlet from the Oklahoma City plant is in a dry gulch, where it is stated that there have been no complaints. There are no data given to indicate the removal of suspended solids or organic matters at this plant.

In *Engineering News* of Mar. 21, 1912, is an article by Mr. H. V. Hinckley, containing a more detailed account of this plant; and also a comprehensive review of this whole subject by the editorial staff.

ELECTROLYTIC TESTS AT LOUISVILLE

In 1896–97 the author had occasion at Louisville, Ky., to study the Harris magneto electrolytic device of that date, and later to study the use of electrolysis in a comprehensive way for purposes of coagulating and purifying the muddy Ohio river water. The magneto attachments of the Harris device were found to be without effect as to the removal of bacteria or organic matters, but the electrolytic treatment by means of iron and aluminum electrodes appealed sufficiently to the Directors of the Louisville Water Co. to cause them to instruct the author to proceed with quite an elaborate series of tests. In fact, some $15,000 were spent at Louisville in studying the electrolytic method from the engineering, chemical and biological standpoints. It was found with the process as there studied that there was little accomplished along the lines of oxidation, but that it did have *merit as a means of coagulating the river water preliminary to subsidence and filtration.*

It is not claimed by any means that the Louisville results are representative of the best that is now to be obtained from this method or that the results could not be interpreted or stated in a more precise way in view of recent advances in the field of electrical engineering and electro-chemistry. However, it is believed that the essence of electrolytic treatment was exploited at Louisville with a thoroughness that justifies an account of it here. Especially is this so as it is the belief of the author that the field of electricity in its relation to purification projects is so firmly fixed in the public mind that the matter will come up from time to time for many years, and that an outline of the Louisville work may be of aid to those who have to deal with careful investigations of this and allied subjects. A full account of the Louisville investigations with estimates of cost of installing the process is found in the author's book on "Water Purification at Louisville, Ky."

STATUS OF THE ELECTROLYTIC DECOMPOSITION OF METAL PLATES

At the outset of this portion of the Louisville investigation the evidence upon this point may be briefly outlined as follows:

1. Copper, lead, tin, and zinc are inadmissible for electrolytic decomposition for this purpose, because the resultant chemicals

are partially soluble in water, and would therefore be liable to injure the health of persons drinking the water after such treatment.

2. Aluminum and iron are the only metals of commerce which can be electrolytically decomposed into chemicals adapted to coagulation. The available information concerning them at that time was as follows:

3. One pound of metallic aluminum, electrolytically decomposed into aluminum hydrate, is substantially equivalent to 1 pound of aluminum in the form of aluminum sulphate, when the latter is applied to a water containing lime or magnesia in solution. One pound of metallic aluminum in sheet form costs 27 cents, and 1 pound of aluminum in the form of sulphate of alumina costs 16 cents. The alumina in the form of the commercial salt, therefore, costs only 60 per cent. as much as in the form of metal plates, disregarding the expensive items of power, electrolytic cells, and waste of metal in the latter case.

4. One pound of metallic iron electrolytically decomposed into iron hydrate is substantially equivalent to 1 pound of iron in the form of persulphate of iron, when the latter is applied to water containing lime or magnesia in solution. One pound of metallic iron, in the form of plates suitably arranged in an electrolytical cell, costs about 2 cents, and 1 pound of iron in the form of persulphate of iron costs 5 cents. There was a difference, therefore, of 3 cents per pound, to cover the cost of electric power and waste of metal. This was a substantial margin on the right side, and it made the electrolytic production of iron hydrate a factor in the problem.

If iron were used in the form of copperas or ferrous sulphate, it would reduce the working margin above given in favor of the electrolytic method.

GENERAL DESCRIPTION OF ELECTROLYSIS

Electrolysis is the name of the process by which a liquid is decomposed by means of an electric current. As a rule, such liquids are aqueous solutions of various chemical salts and compounds which are capable of splitting (dissociating) into two component parts. Liquids which can be electrolyzed are called electrolytes. Absolutely pure water cannot be electrolyzed, practically speaking, and liquids possess this capacity by virtue

of the chemical compounds dissolved in them. These compounds serve as conductors of the electrical current, and electrolytes are called conductors of the second class, in distinction from the metals, which are known as conductors of the first class.

A receptacle in which electrolysis takes place is called an electrolytic cell. The plates attached to the ends of the wires running from the electric generator to the cell and return are spoken of as the electrodes. To distinguish the two plates, or two sets of plates, the electrode by which the electric current enters is termed the positive pole, or anode, and that by which it leaves, the negative pole, or cathode. The dissolved chemicals in the water are dissociated into two component parts, which are called ions. When an electric current is passed through an electrolytic cell the ions move to the electrodes. The metallic (including hydrogen) constituents or ions of the substances dissolved in the water pass to the cathode or negative pole, while the acid ions move to the anode. The former ions are called cathions and the latter anions. This movement toward the respective electrodes, of the metallic and acid portions of the compounds dissolved in the liquid, explains the manner in which an electric current is conducted through ordinary water. Having made this point clear, we will now proceed to consider the most important point in question, viz.: the action of the ions when they reach electrodes of different composition.

Electrodes may be divided into two classes, according to their ability or non-ability to be dissolved by the ions which reach the positive pole, with the formation of new chemical compounds. Some electrodes, such as carbon and platinum, are not dissolved by the anions, which find it easier to attack water and decompose it. Such electrodes are called passive or insoluble. Other electrodes, such as aluminum and iron, form new chemical compounds by the solvent action of the anions, which find it easier, wholly or in part, to unite with the metal electrodes than to attack and decompose water. Such electrodes are called active or soluble. Of the two expressions, passivity and solubility of electrodes, the former is preferred, and hereafter we shall use it exclusively. As implied above, all negative poles, regardless of their composition, are considered to be passive.

Passive Electrodes.—When carbon or other passive electrodes are employed in the electrolysis of a liquid there are no new chemical compounds permanently formed, but the water is

gradually decomposed into its constituent parts, hydrogen and oxygen gases. To illustrate this we will consider the electrolysis with carbon electrodes of a solution of common salt, sodium chloride, in pure water.

When an electric current is applied to an electrolytic cell in which the electrolyte is a salt solution, the electric current is conducted through the liquid by the passage of the sodium and chlorine ions to the negative and positive poles, respectively. When the ions reach the electrodes their electric charges are neutralized, and they find in each case that the carbon poles are *passive* and do not offer any opportunity for chemical combination.

Under these circumstances the second step in the process consists of the ions at each electrode attacking water. At the positive pole the chlorine ions unite with water and form hydrochloric acid (HCl), which remains dissolved in the water, and oxygen (O), which escapes as a gas. The sodium ions at the negative pole also unite with water and form sodium hydrate (NaOH), commonly called caustic soda, which remains dissolved in the water, and hydrogen (H), which escapes as a gas.

If a porous (parchment) partition were placed in the cell between the electrodes, it would be found that the water in the vicinity of the positive electrode becomes more and more acid as the passage of the electric current continues, and the water in the vicinity of the negative electrode becomes correspondingly alkaline. Hydrochloric acid and sodium hydrate have a strong affinity for each other, and in the absence of a partition unite and under certain circumstances form salt, the substance which was started with, and water. This combination of two of the intermediate products to form the original product constitutes the third and last step of the process. Under some conditions this combination results in the formation of hypochlorite of soda. The latter compound was not noted at Louisville, although it may have played a part that was not then appreciated.

It will thus be seen that with passive electrodes, electrolysis of salt solution effects indirectly the separation of water into its component elements, and that by a recombination of other secondary products the original substance is produced, and the process is therefore continuous.

Active Electrodes.—In order to make this parallel with the preceding account of passive electrodes, we will consider the electrolysis of a salt solution when the electrodes are of iron.

Here the first step in the process, the conduction of the electric current by the movement of the chlorine and sodium ions to the positive and negative poles, respectively, is precisely the same as in the foregoing description.

With regard to the second step in the process, the action of the sodium ions at the negative pole is also the same (because all negative poles are theoretically passive), attacking water with the formation of sodium hydrate and hydrogen gas. The action of the chlorine ions at the positive pole shows the difference between carbon and iron electrodes. In this latter case it is easier for the chlorine to dissolve the iron electrodes than to attack water. Under the most favorable conditions iron chloride is formed without any oxygen, and under ordinary circumstances the amount of oxygen formed appears to be very small, and perhaps *nil.*

The third step, the combination of iron chloride and sodium hydrate to form sodium chloride (the initial compound) and iron hydrate, is precisely similar to the corresponding step in the case of passive electrodes. The only difference in this particular is that iron hydrate instead of water (which may be regarded as hydrogen hydrate) is formed.

From the above description it will be seen that the activity of iron and aluminum electrodes makes their use possible as a means of producing hydrates of these metals. The degree of passivity, even of the same metal, with different salts dissolved in the water varies widely under the conditions of practice.

FUNDAMENTAL LAWS AND PRINCIPLES OF ELECTROLYSIS

The leading laws and principles dealt with in this work are as follows:

1. *Faraday's Quantitative Law.*—This law may be expressed in a number of different ways, among which is the following: The amount of an ion liberated at an electrode in a given length of time is equal to the strength (amperage) of the electric current, multiplied by the electro-chemical equivalent of the ion. The electro-chemical equivalent of hydrogen for 1 ampere of current for 1 hour is equal to 0.375 gram (5.78 grains). On this basis the electro-chemical equivalent of any ion may be obtained by multiplying the above figures by the chemical equivalent weight of the ion. In the case of elementary ions, this chemical equiva-

lent weight is the atomic weight divided by the valency, and in the case of compound ions, it is the molecular weight divided by the valency.

From Faraday's law it follows that, other conditions being equal, the amount of hydrate of iron or aluminum formed is proportional to the amperage of the current; and the amount of coagulating chemicals is therefore controlled by regulating the amperage of the current.

2. *Ohm's Law.*—Ohm's law, that the number of amperes of current flowing through a circuit is equal to the number of volts of electro-motive force, divided by the number of ohms of resistance in the entire circuit, holds good for electrolytic construction.

3. *Resistance of Electrolytic Cell.*—In view of the fact that it is the amperage of the current and not its potential which determines the rate of formation of hydrates, it is obvious that the resistance of the cell should be kept as nearly as possible at a certain minimum for economical reasons. The minimum potential is determined by the polarization of the cell, as stated more fully in a following paragraph. The resistance of the cell is due to several factors, among which are: the area of electrodes; the distance between electrodes; the amount of dissolved salts in the river water (electrolyte); and the formation of non-conducting coatings on the electrodes. From Ohm's law it follows that the resistance of an electrolytic cell increases directly with the water space between the electrodes, and inversely with the cross-section of the electrolyte (or area of the electrodes).

4. *Resistance of Ohio River Water.*—During the period of flood in February and March, 1897, the resistance of the river water increased nearly threefold, due to the decrease in amount of dissolved chemical compounds. The suspended matters in the water, including those partially dissolved constituents, exerted no influence on the conductivity.

Estimating the conductivity or resistance (which is the reciprocal of the conductivity) of the river water from the observations on different combinations of various solutions of the salts normally present in it, the resistance in ohms per centimeter cube should be theoretically 6100, 930 and 2080 ohms for maximum, minimum, and average, respectively, corresponding to 72, 260 and 122 parts per million of dissolved chemical compounds, not including carbonic acid gas. As will be shown in connection with the study of passivity of iron electrodes, it is not possible to

draw specific mathematical conclusions in regard to the behavior of combinations of ions, based on the results of observations in individual ions. It will be also shown in this connection that dissolved carbonic acid gas is only very slightly ionized, and from a practical point of view need not be considered as a conductor at all.

It is therefore necessary to rely upon observations on the river water itself, though as will be seen, the theoretical and observed resistances follow closely the same curve.

5. *Polarization of Electrodes.*—When a current of electricity flows through an electrolytic cell, and causes changes in the electrolyte, or on the electrode, the electromotive force of the current is thereby reduced. This action is known as polarization. In explanation of this point, which determines the minimum potential of current that can be safely employed, it is to be stated that all ions possess a certain force or intensity of fixation wherewith they attempt to retain their electric charges when they reach the electrodes. Accordingly, a certain potential, slightly above that corresponding to the intensity of fixation, is necessary in order to overcome this force, and free the ions at the electrodes of their electric charges. The existence of this intensity of fixation, with an opportunity to measure it, is shown by the reverse current which takes place for a short time when the primary current is shut off. With active electrodes, polarization becomes less marked. The potential of polarization varies in the line of work in question. So far as we know, there would be no case where the polarization would require over 2.35 volts to overcome it. Ordinarily it would be much less than this. Records show that in the investigation of electrolysis of iron pipes lying in the ground near electric lines of street cars (a subject similar in a measure to the present one), decomposition of the iron has taken place at a potential of only 0.001 volt. In all cases a difference in potential of 2.5 volts or less between adjoining electrodes, would suffice to overcome the intensity of fixation of all ions, while much less than this would probably be adequate for a majority of the ions. Practical investigations along this line are recorded later, where it will be seen that potential differences as low as 1.0 volt can be safely employed with iron electrodes.

6. *Passivity of Electrodes.*—As already stated, all negative electrodes, so far as is known, are passive to the ions, and certain

positive electrodes such as iron and aluminum, are active. From Ampere's law it follows that the same quantity of electric current always causes in electrolysis the same equivalent amount of acid ions (anions) to go to the positive electrodes, and have their electric charges neutralized. They then pass into the atomic state. With passive electrodes, they attack water, and equal currents produce equal amounts of oxygen gas. Provided that active electrodes were completely active (not at all passive or insoluble under the action of these liberated acid atoms), the amount of metal decomposed from the positive electrode would also be proportional to the amperage of the current, and to the amount of liberated acid ions, in accordance with Ampere's law.

In the case of iron and aluminum electrodes, however, experience shows that the metal of the positive electrodes is not dissolved in quantities proportional and equivalent to the total quantity of acid ions liberated at the positive electrode. From a practical point of view this fact is a matter of vital importance because it relates to the amount of hydrate formed, and consequently to the commercial merits of the process. Stating this in another way, we may say that only a portion of the current forms the hydrate of the metal used as the positive electrode; and therefore such metals as iron and aluminum are only partially active, as a portion of the current causes the formation of oxygen, just as in the case of completely passive electrodes, such as carbon or platinum.

It follows from the above statements of facts that, under practical conditions, iron and aluminum electrodes are only partially active, and when employed in this process utilize efficiently only a portion of the current. Hence use must be made of degree of activity or passivity of the electrode.

The degree of passivity of iron and aluminum electrodes is due to the two following factors:

1. The initial passivity of the metal to the various acid ions naturally present in the river water. Thus it is well known that hydrochloric acid has a higher solvent action on these metals than carbonic acid.

2. The acquired passivity of the metal to the various acid ions, due to the formation of thin films of metallic oxide, caused by the oxygen formed by the weaker ions, upon the metal.

In practice the varying composition of the river water caused a wide range in the relative amounts of the different acid ions,

and the consequent total dissolving action upon the electrodes. Experience shows that another important factor, especially in the case of aluminum, is the fact that the film of metallic oxide on the positive pole causes a material increase in the resistance which the electric current meets in its passage through the cell. In the case of iron electrodes, however, this is relatively slight, owing to the fact that the film cracks and falls off in scales at frequent but irregular intervals.

7. *Secondary Reactions.*—Normally there are formed with active electrodes a hydrate of the metal, hydrogen, and, varying with the degree of passivity, a certain amount of oxygen. These reactions have been explained in the foregoing account of electrolysis, and may be called primary reactions, or perhaps the primary group of reactions. Other reactions (independent of coagulation), called secondary reactions, will now be referred to.

When iron electrodes are employed the iron is dissolved from the plates in the form of ferrous or unoxidized salts, which would be converted into the partially soluble ferrous hydrate by the alkaline hydrates coming from the negative electrode. Accordingly, oxygen is necessary in order to convert the ferrous into the ferric forms. As practically all of the electrolytically formed oxygen attacks the positive iron electrodes, it is necessary that the atmospheric oxygen, naturally dissolved in the water, serves to effectthis oxidation. This oxidation is necessary in order to convert the iron into a completely insoluble form, so that it can coagulate the suspended matter in the water without any dissolved iron passing through the filter into the purified water.

The secondary reactions in the case of aluminum electrodes are less clearly understood, but are referred to later in this chapter.

Concerning hydrogen at the negative electrode, small portions of it in the nascent condition combine with atmospheric oxygen dissolved in the water, and reduce iron compounds and nitrates; while the bulk of it, after saturating the pores of the metal, escapes as a gas in a molecular condition.

CAUSE OF PASSIVITY—INITIAL AND ACQUIRED

Some experiments were made with new bright wrought-iron and old (rusty) iron electrodes. Both sets were cut from the same plate, and one set cleaned to bright metal while the other remained rusty. That new bright iron behaves differently

toward the several ions was clearly shown, and while it is difficult to account for the results over 100 per cent., it seems clear that in the case of all but hydrochloric acid a certain percentage of the electric current is not directly utilized in dissolving the metal. The explanation of this lies in the relative affinities of these ions for the metal and for water. When the electric current is transferred by means of the ions and the ions are discharged or neutralized at the positive pole, they attack the water of the electrolyte and the metal in the proportion of their affinities for the liquid and the metal. The acid ions which attack the water can be said to represent the passivity of the iron, because they would attack the iron were it not passive. The results on new iron may be taken to indicate the relative passivities which bright iron has to the several acid ions. The data are not sufficient, however, to warrant the use of these figures except in a comparative manner.

Those ions to which the metal is passive attack and decompose water, setting free oxygen gas in a nascent condition. Between this gas and the metal there is at all times great affinity, and therefore a considerable amount of the oxygen attacks the metal and forms the oxide. As this continues the plate becomes covered with a coating of oxide scale which grows thicker and thicker until it begins to crack off. Practically speaking, the rate at which the scale is removed from the plate by cracking and peeling becomes eventually as great as the rate of its formation, and equilibrium is established with reference to the respective attacking of the metal and of water.

The presence of this oxide scale changes the relation of the acid ions to the metal, as they must either attack and dissolve the oxide or pass through the scale to attack the pure bright metal beneath. As either of these processes requires more energy than the simple solution of the metal, an increased percentage of the ions does not attack the metal, but decomposes water, and by this action the iron has an *acquired passivity*.

During the process of formation of the scale and before equilibrium has been established between the formation of the oxide and its scaling off, the acquired degree of passivity increases rapidly as the scale forms.

As the formation of the oxide is dependent on the passivity of the metal and this in turn increases with the oxide present on the face of the plate, the process is a reciprocal one, one action increasing the other. For this reason the length of time elapsing

between the beginning and end of the action (establishment of equilibrium) is comparatively short and is dependent upon the density of the current used. Furthermore, it is probable that the passivity of the metal may become greater before the scale begins to come off than it is after equilibrium has been established.

The results with old iron may be taken as fairly representative of the total passivity of iron as it would be used in practice.

As will be presented beyond, there are no indications to warrant the belief that the potential difference between the plates has any effect upon the passivity of the metal.

Within the limits employed in these investigations the difference in initial passivity due to the composition of the metal was not apparent, cast-iron, wrought-iron of different grades, and mild steel all giving apparently parallel results, or very nearly so.

FORM IN WHICH IRON LEAVES THE PLATES

The iron leaves the positive electrodes only, and in order to make the full set of plates serviceable it is necessary to reverse the electric current from time to time.

At the positive electrodes the iron leaves the plates in two ways, namely:

1. Those acid ions, which are neutralized electrically at the pole by dissolving some of the metal, form iron salts of the various acids, such as iron chloride, iron sulphate, and iron carbonate. These compounds, furthermore, are in the ferrous (unoxidized) condition, as explained in the next section.

2. Those acid ions which, by virtue of the degrees of passivity of the iron anode, find it easier to react with water upon neutralization than to dissolve the equivalent amounts of iron, form oxygen. This oxygen unites largely with the iron to form iron oxide, which appears as films.

In the first case the solution of iron is regular and proportional to the amperage of the current when the degree of passivity is constant. With those ions to which the iron electrode is passive the formation of films of iron oxide is regular, but the films crack and peel off from the electrode in an irregular manner.

INFLUENCE ON THE PROCESS OF OXYGEN

With the Ohio River water the oxygen in an electrolytic cell comes from two sources, the atmospheric oxygen naturally

dissolved in the water, and the oxygen which is formed electrolytically at the anode. We shall consider them separately.

Atmospheric Oxygen.—The atmospheric oxygen performs a very important part in this process by virtue of the fact that it unites with the ferrous compounds as they are dissolved from the electrode, and changes them to ferric or oxidized salts of iron. Apparently this action takes place partly before the iron salts are acted upon by the alkaline hydrates coming from the negative pole and partly after this reaction.

The result is that after the completion of the secondary group of reactions, the dissolved iron is converted into the form of insoluble ferric hydrate, which is an excellent coagulant. The importance of this oxidation from a practical point of view is great, because without it ferrous hydrate alone would be formed; and, owing to its partial solubility, there would be difficulties arising from its passage through the filter.

A small amount of atmospheric oxygen also unites with hydrogen, which is given off as a gas at the negative electrodes. As this combination cannot take place except when the hydrogen is in the nascent state, the action is confined to the oxygen in the immediate vicinity of the cathode.

Electrolytic Oxygen.—So far as could be learned, practically all of the oxygen which is formed at the anode by the decomposition of water attacks the metal electrodes and forms films of iron oxide. As stated above, these films crack off and leave the cell in an irregular manner.

Of course the scales or films of iron oxide are of no assistance in the purification of water.

Comparing the influence of the oxygen from the two sources we see that the atmospheric oxygen performs a very important part, and without it the process could not be put in practice with satisfactory results. The influence of the electrolytic oxygen and the factors which produce it, on the other hand, is a very serious drawback to the process, because it means a large waste of electric power and of metallic iron. The amount of power and of metal wasted is shown beyond.

INFLUENCE ON THE PROCESS OF HYDROGEN

Under all conditions hydrogen gas is produced at the negative electrode in amounts proportional to the formation of alkaline hydrates. Owing to the fact that iron possesses the capacity to

occlude large quantities of hydrogen gas within its pores, a portion of the hydrogen is disposed of in this manner, and there are reasons for believing that the negative electrode after a time is practically composed of hydrogen, from an electrical point of view. A small portion of the hydrogen when in a nascent condition unites with atmospheric oxygen to form water. The bulk of it, however, after the saturation of the pores of the iron cathode and of the water, escapes as a gas.

INFLUENCE ON THE PROCESS OF THE SOLUBILITY OF THE INITIAL IRON COMPOUNDS

It has been stated that when the iron is first dissolved from the positive electrode the compounds are in a form of soluble ferrous salts. Experience shows that some of these iron salts, before they are converted into insoluble ferric hydrate, become conductors of the electric current just like lime and other salts dissolved in the water. The result of this is that a portion of the iron is conducted to the negative electrode; and, in a manner similar to that in electroplating, is deposited there in what appears to be a metallic form.

From a practical point of view the influence of this state of affairs is to cause a waste of electric current, as no good is accomplished by transferring the metal from one pole to the other. So far as could be learned this metal is not wasted, but is available for electrolytic decomposition when the direction of the electric current is reversed.

INFLUENCE OF DIFFERENCES IN POTENTIAL

Within the limits of accuracy no difference could be found in the rate of hydrate formation at the several potential differences.

It was therefore concluded that potential differences between the limits of 1.0 and 220 volts exerted no apparent influence on the rate of formation of hydrate; that scale and gas formed with apparently the same rapidity at all potential differences, and that the practical limits of construction with references to the area of electrode surface and length of electrolyte would be the controlling factors in determination of the potential difference to employ in practice.

INFLUENCE ON THE FORMATION OF HYDRATE OF CURRENT DENSITY

The current density ranged from 0.30 to 2.08 amperes per square foot of active electrode surface during these tests. For

the most part it was about 1.04 amperes with the large devices. In the case of some laboratory experiments a current density as high as 50.4 amperes per square foot was employed at times, but the usual density was about 15 amperes per square foot.

In connection with the low potential experiment described above, current densities as low as 0.26 ampere per square foot were employed.

Within these limits no marked influence of current density upon the formation of hydrate was noticed, but it is probable, as noted above, that the deposition of iron at the negative pole was somewhat greater with the high than with the low densities, though the increased rapidity of replacement of electrolyte due to increased flow of water through the cells would probably compensate for this in a measure. Theoretically, as has been explained above, the lower the current density the lower the rate of deposition of metal on the negative pole. Current density as low as admissible with economic construction of cells should therefore be employed.

INFLUENCE ON THE FORMATION OF HYDRATE OF REVERSING THE DIRECTION OF THE ELECTRIC CURRENT

When the direction of flow of the electric current passing through the electrodes and electrolyte is reversed, the positive electrode (which was previously the negative) is at the outset saturated with hydrogen gas and the surface is coated with metallic iron, probably mixed somewhat with suspended matters from the water. Comparison in the last set of tables of the amount of iron in the water as it left the cells before and after reversals of current on July 23 at 4:00 P. M., and on July 28 at 4:15 P. M., shows that in three of the four instances the rate of decomposition of iron suffered a marked diminution for more than an hour. The cause of this is not clearly understood, but it appears to be associated with the occluded hydrogen in the pores of the metal and with the surface coatings, which will vary of course with the frequency of reversal and the character of the river water. In practice these marked diminutions in the formation of hydrate would be a serious matter and for a time would require the operation of a reserve portion of the plant, both with regard to the cells and the generating appliances.

EFFECT ON THE SUBSEQUENT FORMATION OF HYDRATE OF ALLOWING ELECTRODES TO REMAIN OUT OF SERVICE

When the electric current was shut off from the electrodes and the cells kept full of water it was repeatedly noted that the decomposition of iron and formation of gas continued for a long time. This was due to a galvanic action, the metal being electropositive to the surface coating of oxide. During the month of April and early part of May, when the electrical devices were out of service on numerous occasions while tests with chemicals were being made, it is estimated that the total weight of the electrodes decreased 65 pounds, due to this factor alone. On the grounds of economy and of comparable conditions for reliable data, it became necessary to drain the water from the cells as soon as the electric current was stopped. So far as is known, the subsequent formation of hydrate, when the electric current was applied following a period of rest in which the electrodes were covered with water, was not seriously influenced by this procedure, which, however, for the reasons stated above, was found to be impracticable.

After the first of June the water was drained out of the cells as soon as the current was turned off. In consequence of the action of the air it was found that the rusting of the electrodes thus produced increased the acquired passivity of the iron, and when the electrodes were again put in service the rate of formation of hydrate was abnormally low for a time. This is shown by the results on the morning of July 24, when, following a rest after draining the cells of about 41 hours, the electrodes did not yield the normal amount of iron for 0.5 or 0.75 of an hour. In other cases, where the period of rest was longer the evidence shows a more prolonged diminution in the rate.

PERCENTAGE OF METAL WASTED IN THIS PROCESS

When the potential difference of the current between adjoining plates was three volts or more the evidence showed a rate of decomposition of iron on the positive plate equivalent to about 100 per cent. of the theoretical rate of 1.05 grams, or 16.2 grains per ampere-hour. Of this iron an amount equivalent to about 10 per cent. of the theoretical rate was found deposited on the negative plate. The amount of iron leaving the cell in the form of available hydrate seemed to vary considerably, but averaged

about 40 per cent. of the theoretical rate. Taking into consideration the fact that eventually the plates become too thin for use and have to be discarded, it seems fair to conclude that in this process of producing iron hydrate substantially one-half of the metal is wasted by passing into the water in the form of non-hydrated and non-available scales of iron oxide.

The experiments of Sept. 28 to 30 indicate that no substantial advantage in this respect would be obtained with potential differences as low as 1 volt.

RESISTANCE TO THE PASSAGE OF ELECTRIC CURRENT OF FILMS OF IRON OXIDE

The results of analyses and of observations of scales in the water leaving the cells showed that the films of iron oxide attached to the positive electrodes remained there only temporarily, and came off at an irregular rate from time to time. In consequence thereof it is not probable that the entire surface was covered at any one time, in the course of regular operations, with a film which very materially increased the resistance of the electrodes. Compared with new metal the plates doubtless offered a certain resistance, but within the ranges of service to which these electrodes were subjected the increase in resistance was within the limits of observation, or less than 1 volt at 400 amperes or .0025 ohm.

PERCENTAGE OF ELECTRIC POWER WASTED IN THIS PROCESS

Under the above-described conditions of operation, with potential differences between the electrodes of 3 volts or more, the evidence shows that between 50 and 60 per cent. of the electric current was wasted in removing iron in the form of scales, due to the formation of oxygen at the surface of the plates, and in depositing some of the available metal upon the negative electrodes. This does not include the effect of scales in offering increased resistance to the electric current, as noted in the last paragraph. Combining the three items, the waste of electric power may be safely placed at 60 per cent.

CONCLUSIONS AS TO IRON ELECTRODES

From the evidence presented here it may be concluded:

1. Under practical conditions this process can be used to produce ferric hydrate, a good coagulant, up to the point where

the atmospheric oxygen dissolved in the water is not completely exhausted.

2. The evolution of gas is fairly small, comparatively speaking, but the indications were that at times the gas might exert a retarding influence upon subsidence and a clogging effect upon filters.

3. The rate of production of ferric hydrate was reasonably uniform at its minimum limit except for periods in the vicinity of one hour following a reversal of the direction of the current and an exposure of the plates to the atmosphere.

4. Owing to galvanic action when the coated plates were allowed to remain in water when out of service, the loss of metal made it imperative to avoid this procedure except for very short intervals.

5. Under conditions of good practice the amount of metal wasted as oxide scale would be substantially 50 per cent.

6. Under conditions of good practice the amount of power wasted would reach about 60 per cent.

CONCLUSIONS AT LOUISVILLE AS TO ELECTROLYTIC FORMATION OF ALUMINUM HYDRATE

With the present knowledge of electro-chemical actions, and with the present cost of aluminum in the form of plates as contrasted with equal amounts of metal in the form of commercial sulphate, the use of hydrate of aluminum prepared by the electrolytic decomposition of the metal is out of the question on account of cost. This is shown by the following summary:

1. Aluminum in sheet form costs in carload lots according to current quotations 27 cents per pound. In the form of sulphate of alumina one pound of metal costs 16 cents. The ratio of cost of equal amounts of coagulant prepared by the electrolytical decomposition of the metal and by the chemical decomposition of the commercial sulphate by lime is therefore 17 to 10 for aluminum alone.

2. In operating there would be a constant loss of about 50 per cent. of the metal required for the formation of the hydrate due to the passivity of the electrodes to the acid ions, the supplementary solvent action of the salts formed, and the consequent formation of oxide scale. This might at times approach 100 per cent.

3. The amount of power required would constantly increase

with the age of the electrodes, necessitating at frequent intervals the removal and scraping of the plates. This last step would be very expensive. Under normal conditions probably 50 per cent. of the normal power required would be wasted in overcoming the resistance of the surface coatings. The normal amount of power would also be increased from 50 to 100 per cent. to offset the reduced rate of formation of hydrate, due to the acquired passivity of the metal.

4. In short, the process was impracticable under the conditions of these tests, both with regard to economy and regularity of production of hydrate. While it is probable, if not certain, that prolonged investigation would improve the process by using a different grade of metal and devising mechanical appliances for the removal of scales, yet in the light of our knowledge, owing to the inherent character of the metal and the narrow range of conditions as applied to this line of work, commercial success of this process seems to be an impossibility.

MODIFICATIONS IN ELECTROLYTIC APPARATUS

There are a number of companies who are exploiting modifications in apparatus for the electrolytic treatment of water and sewage. Recently there has come to the attention of the author the devices of the Electrolytic Purification Company of Philadelphia, Pa. They are putting on the market for small installations apparatus which has paddles or scrapers mechanically operated between the electrodes. The purpose of these is to keep the plates clean, to mix the gases with the water and insure more complete contact with the impurities therein. It is also understood that this apparatus is connected somewhat differently from that which has been in general use hitherto. This is mentioned to show the extent to which this subject is receiving active consideration.

THE CHLORIDE PROCESS OF MR. W. B. BULL

In the *Proceedings of the Illinois Water Supply Association* for 1911, page 66, a description is given by Mr. W. B. Bull of a new method for the preparation of coagulating chemicals. Use is made of an electrolytic cell with graphite electrodes between which is placed an asbestos diaphragm. A solution of salt is

slowly fed to the cell and there is removed from the cathode portion of the cell caustic soda which may be recovered in form to place upon the market as a by-product. From the anode compartment there is removed a solution containing some chlorine and perhaps hydrochloric acid, the exact composition of which is not known. It is of an acid nature, however, and is conducted from the cell through receptacles containing iron borings. A salt of iron, said to be largely perchloride of iron, is obtained. It is stated that the device allows very economical production of an efficient coagulating chemical. The cost of current, salt and scrap iron is offset in large installations, according to the inventor, by the sale of the soda by-product.

The device has not passed beyond the experimental stage, although in a paper before the Indiana Sanitary and Water Supply Association, February, 1912, it was stated by Mr. Bull that a cell has been obtained which meets the requirements sought. This paper appears in *Municipal Engineering*, March, 1912.

ELECTRICITY IN DIRECT OXIDATION PROCESSES

It is not to be inferred from the foregoing statements that electricity cannot be used for the direct oxidation of a substantial portion of the unstable substances in sewage. This can be accomplished, but it is preferable to do so not with electrolytic devices as herein described at length, but with other arrangements designed to produce hypochlorites either from salt solutions or sea water. Hypochlorites and atomic oxygen were perhaps a factor at Louisville, but if this was the case they did not force themselves to the attention of the author either in the destruction of bacteria or of organic matter.

Direct oxidation may also be effected with the aid of ozone produced by means of electricity. Hypochlorite treatment and ozonization are made the subject of brief chapters in the latter part of this book.

RÉSUMÉ

Electrolytic treatment does not seem to afford a practical means of direct oxidation of organic matter in sewage so that the latter will be stable or non-putrescible. In fact, a substantial removal

of organic matter is not a function of this process as applied up to this time.

To some extent, however, oxygen is given off and this may aid in deodorizing sewage and reducing the quantity of unstable organic matter.

As an aid to sedimentation, electrolytic treatment with iron electrodes is capable of practical use. There is no economy in this over the use of salts of iron now on the market. Aluminum electrodes are prohibitively expensive.

The Bull process of using electricity to separate the acid ions of salt solution for use in making perchloride of iron, with a recovery of caustic soda as a by-product seems to offer some hope of practical merit. It is not beyond the experimental stage.

With any form of electrolytic treatment, sedimentation with or without filtration should be employed.

Direct oxidation of the fairly unstable organic matters of sewage may be secured with the aid of electrolytic treatment through the preparation of hypochlorites, as described later. This is essentially a sterilizing procedure and not aimed at the production of a stable effluent.

Electricity may also be used in sewage treatment through the preparation of ozone. This has received considerable discussion at intervals, but it is not on a working practical basis at the present time. It is briefly mentioned in a later chapter.

CHAPTER XVII

STRAINERS, SLATE BEDS AND COLLOIDORS

Strainers, roughing filters, colloidors and other devices for the mechanical or physical separation of suspended matters from sewage have received attention from time to time in America, although there are few or none now in practical service. Some have been studied from the viewpoint of European experience, and roughing filters are now being built at Atlanta to separate suspended matters from the effluent of Imhoff tanks preparatory to application to sprinkling filters.

From the theoretical standpoint these devices are of importance in illustrating some phases of the theory of sewage purification. They occupy an intermediate position between screens and sedimentation basins, on the one hand, and the oxidation or nitrifying beds such as sand filters, contact filters and sprinkling filters, on the other. In relation to different theories of the behavior of the latter devices, roughing filters and colloidors are of sufficient importance to justify a short chapter.

HISTORICAL DEVELOPMENT

In the early stages of sewage treatment in the United States efforts were made to separate the solid matters from the sewage by different contrivances. The subject is well reviewed by Messrs. Rafter and Baker up to the date of the appearance of their book in 1894.

One of the first strainers was installed in 1886 at Medfield, Mass., under the supervision of Mr. Fred Brooks. This plant, as described by him in the Report of the Massachusetts Board of Health for 1886, has treated the wastes from a straw factory to which have been added the sewage of some houses. Much ground dyewood reached the sewers, and before its application to intermittent sand beds the sewage was passed upward through layers of compressed excelsior supported between wooden slats. Mr. Brooks states that the device worked quite satisfactorily

during the first year, at the end of which the excelsior had become so rotted that it was necessary to renew it.

Other straining devices were tried for a time at Atlantic City and Long Branch, N. J.; Leadville, Colorado, and elsewhere, as described by Messrs. Rafter and Baker. Their impracticability probably related to clogging and perhaps to shortcomings in the clarification.

Early Lawrence Experience.—Beginning in 1894 strainers of fairly fine coke of a depth of 1.5 to 8 inches were used for the removal of suspended matters from sewage. When clogging resulted it was the plan to remove the accumulated sludge and filtering material at the surface and after air drying to consider its availability for fuel purposes under boilers. Results are summarized in the report for 1894, page 538. It appears that it is feasible to clarify sewage in this way to a somewhat greater extent than that obtained with plain sedimentation. In fact, the removal of organic matter seemed to be from 50 to 100 per cent. greater than in settled sewage. On the score of cost the Lawrence data are not conclusive. The clogged material amounted to about 5 cubic yards per million gallons. The tests have been merged into studies for the removal of the retained organic matters from filters of various kinds by aeration, oxidation and nitrification.

Gardner Experience.—On a practical scale coke strainers were put in use in 1901 at Gardner, Mass., where there were four strainers, each 0.125 acre in area. The material was 15 inches thick, composed of 6 inches of graded crushed stone which supported 9 inches of fine coke breeze (0.41 millimeter effective size). About 300,000 gallons of domestic sewage were applied daily, with the result that about 70 per cent. of the total organic matter was removed in this way during the warmer season of the year. The surface required cleaning about once in 10 days, the material removed equaling about 2 cubic yards per million gallons. Frost prevented the filters from being cleaned at such frequent intervals, and during the winter these strainers went out of service early in January. Although it is necessary in such a climate to cover such strainers for winter service, it does not necessarily eliminate this treatment from practical consideration under some conditions. It is stated that these devices at Gardner have been of very little or no practical use.

Aerated Roughing Filters.—Beginning in 1892 efforts were

made to increase the efficiency of gravel filters at Lawrence by means of aeration. Air was artificially drawn through the filtering material, in some cases in an upward direction and in others in a downward direction. In all cases these filters clogged so as to indicate decisively that artificial aeration, while beneficial to a certain degree, was not helpful in proportion to its cost unless power was available at nominal expense.

The late Col. George E. Waring, Jr., tested similar devices at Newport, Rhode Island, during 1894. Such devices were also installed by him in connection with other portions of the patented Waring system at Willow Grove, near Philadelphia; East Cleveland, Ohio, and a number of small places elsewhere. So far as known, experiences on a practical scale led to no other conclusion than that stated above for the Lawrence investigations.

Columbus Experience.—At the Columbus testing station, as described in Mr. Johnson's report of 1905, pages 139–51, sewage was passed through two coke strainers. In each case the material was 18 inches thick, the particles averaging about 0.25 inch in size. The coke was supported by a 12-inch layer of graded gravel. The strainers were at first operated continuously with a depth of about 2 inches of sewage over the surface of the material for seven days at a time, followed by a rest on every eighth day. At the end of a few weeks, however, the schedule was changed so that the strainers were alternately operated and rested for 12-hour periods. During severe winter weather it was necessary to operate continuously the strainer which was placed out of doors. The nominal rates of filtration were 1.0 and 3.0 million gallons per acre daily, respectively.

Septic action was a characteristic feature of these devices. In fact, anaerobic decomposition caused a pronounced odor of sulphureted hydrogen about the discharge pipes to a more noticeable degree than with any other devices. Perhaps this was related to action on the sulphur in the coke.

These strainers removed on an average about 64 and 81 per cent. of the total suspended matter in the effluent of the grit chamber. The lower removal was influenced undoubtedly by the higher rate of filtration. Compared with plain sedimentation, the strainer with the higher rate gave approximately equal clarification. Unequal frictional resistance due to unequal clogging caused at times so-called "breaks" in the deposits at the

strainer surface. This resulted in the flow of sewage through limited areas at abnormally high rates, which naturally caused a sharp deterioration in the quality of the effluent.

The Columbus strainer operated at the high rate required scraping at intervals of 13 to 63 days. The other strainer was scraped after periods of service of 228 and 14 days, respectively. After the second scraping, however, it became so clogged in 17 days as to cause the removal of the entire depth of material. These strainers were operated with an effective head of about 3 feet before scraping was resorted to.

The volume of scrapings averaged about 5.5 cubic yards per million gallons of sewage strained. It did not seem to be feasible at Columbus to reclaim the coke by washing. After sufficient air drying it was considered feasible to burn the clogged coke under boilers. Combining the expense of handling such relatively large volumes of clogged material with the objectionable odors encountered, and the serious weakness of the device through the "breaks" and unloading of suspended matter into the effluent, it is not probable that strainers for the treatment of unsettled sewage could be advantageously adopted for large plants.

Later Lawrence Tests.—In the 1910 Report of the Massachusetts, State Board of Health, page 242, Messrs. Clark and Gage describe the results of tests with Strainer E. It contained 12 inches of buckwheat coal and had been in service for 9.5 years, at an average rate of about 1 million gallons per acre daily. During this interval it was scraped only twice and raked or disturbed only four times. This result is remarkable and indicates this coal layer was much more of a filter than a simple strainer.

Atlanta Plants.—One of the features of the Atlanta disposal works, placed under construction in 1911, is the use of strainers or roughing filters to remove certain suspended matters in settled sewage from Imhoff tanks before its application to sprinkling filters. Alternate bids were received on fine screens (see Chapter XII) and roughing filters to serve this purpose. The screens are being installed at the Proctor creek plant and roughing filters at the Peachtree creek and the Entrenchment creek plants. The latter devices follow the general practice adopted by Mr. James Corbett at Salford, England, and extended by Mr. Watson at Birmingham, England, in connection with sprinkling filters.

ROUGHING FILTERS AT ATLANTA

In the *Engineering Record* of Dec. 31, 1910, will be found a description of a plant which at that date had just been placed under contract. This installation is known as the Peachtree creek plant and was designed by Messrs. Hering & Fuller. Fig. 46 shows the general detail of the roughing filters proposed by Mr. Rudolph Hering. As shown in the figure, they are ar-

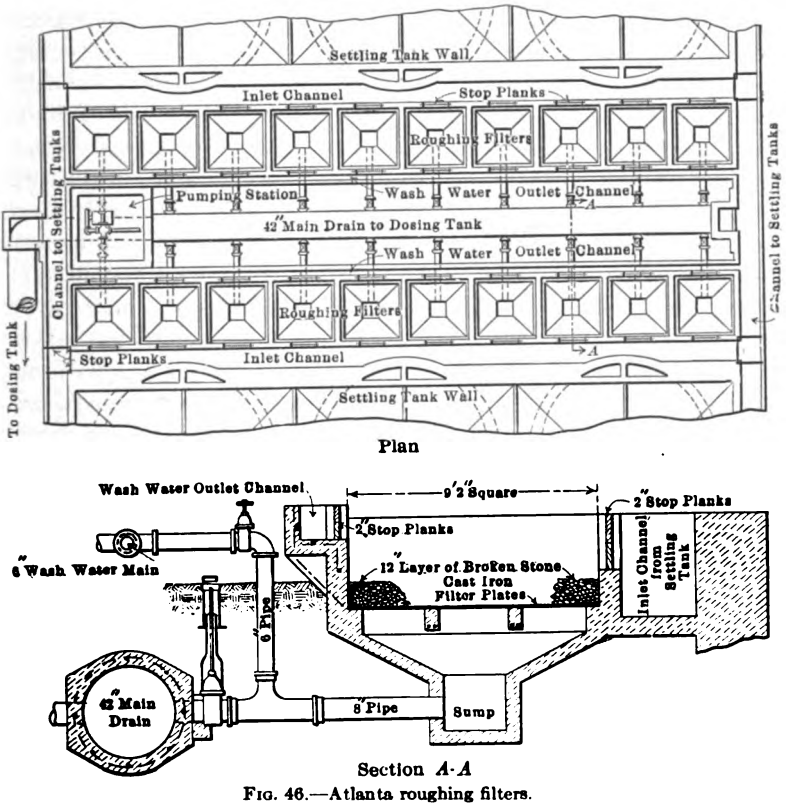


FIG. 46.—Atlanta roughing filters.

ranged in two groups of two batteries of 10 units each on either side of a 42-inch drain-pipe leading to the dosing tank and sprinkling filters. Each pair of the double rows of roughing filters is placed between units of the two-story settling tanks of the Imhoff type, and the inlet and outlet channels of the roughing filters are parallel with the direction of flow through the Imhoff

tanks. The total area of the roughing filters is about 3360 square feet for the 40 units. The filtering material consists of a layer of 0.50 to 0.75 inch stone, 12 inches thick, supported on cast-iron plates perforated with nine-sixteenth-inch square holes. Each plate is about 1.5 by 3 feet in area, weighing approximately 80 pounds. They are supported at the end on concrete ledges along the side of the filters and by two reinforced concrete beams. The filtering material in each square unit measures at the surface about 9 feet 2 inches on a side. The normal rate of filtration when the plant is working at full capacity is intended to be about 175 million gallons per acre daily, or about 2.8 gallons per square foot per minute. It is proposed to wash these filters when the acting head to overcome friction reaches about 2 inches, although if necessary the total loss of head may reach 1 foot.

These filters will be washed in a manner similar to mechanical water filters. The rough filtered sewage will be pumped through a 6-inch pipe to the lower side of the perforated cast-iron grid through which the water under pressure will pass. It will overflow through a special outlet channel leading to the inlet end of the Imhoff tanks. Thus all of the removed suspended matter will be discharged into the sedimentation chambers, with the coarser matters passing to the digestion chamber for septicization. The clarified portion of the wash-water will pass from the Imhoff tanks through the roughing filters again and thus to the sprinkling filters. None of the dirty wash-water can leave the plant without complete passage through a full set of sedimentation and filtration devices.

There can be no doubt about these devices being able to remove the floating matters that may reach them from the settling tanks. Whether or not this is the cheapest way of protecting the sprinkling filters against nozzle clogging and surface clogging is a question for the future. The method will no doubt vary in its suitability with different local conditions. To what extent these devices will remove finely divided suspended matter, non-settling solids, or colloidal matter from the settled effluent cannot now be stated. There will probably be an appreciable removal as the devices continue in service and become ripened. They will require careful management and fairly frequent washing. If these roughing filters are not washed fairly frequently, and the loss of head is allowed to exceed small limits, there is danger of "breaks" occurring. If such

should happen, it would defeat the purpose of the devices, as in a few moments solid matters might reach the nozzles and surface material of the sprinkling filters so as to produce serious clogging.

SLATE BEDS

In England the Dibden slate beds have attracted much attention as a preliminary treatment for sewage. The main feature of Mr. Dibden's work relates to the aerobic treatment of the sewage undergoing sedimentation and of the sludge undergoing digestion. In this respect the process when worked at its best differs distinctly from septicization in one-story tanks.

As clarifying devices recent publications indicate that the suspended solids were reduced by slate beds to the extent of 66.6 per cent. at Devizes, 47.5 at Dereham, and 27.4 per cent. at Machynlleth. It is stated that the sewage at Devizes is strong, that at Dereham is weaker, and that at Machynlleth weaker still.

These beds are arranged differently in different cases. Normally the slates are arranged horizontally and spaced it is said about 2 inches apart. The voids range from about 66 to 90 per cent., depending upon the thickness of the slate and their spacing. A 2-inch spacing is stated to be most favorable. These beds have been operated on the fill and draw plan, much after the fashion of contact beds, with the development of which Mr. Dibden was intimately connected. The number of fillings ranges from one to three per day, depending upon the strength of sewage and other factors. The rate at which the beds are drained has much to do with their degree of clarification and the quality and quantity of sludge.

The Fifth Report of the Royal Commission on Sewage Disposal rated these slate beds as quite similar to septic tanks in the work accomplished. Later studies by the Commission led to the statement in their seventh report, published late in 1911, that there is a difference between the slate bed sludge and septic sludge in that the former possesses only a slight odor.

The deposition of suspended matters upon the horizontal slate surface in each of the numerous small compartments and the access which this sludge has to air promotes what Mr. Dibden calls aerobic disposal. What the detail is bacterially we do not know, but the evidence shows clearly that larger forms of life than bacteria, particularly red worms, have much to do with the

digestion of the sludge. It is stated that at High Wycombe the air-dried sludge called "humus" amounted to only about 1 cubic yard per million United States gallons, where the sewage has a flow equal to about 36 United States gallons per capita daily.

The freedom from objectionable smells is a question that seems to be somewhat in debate. The results evidently vary at different places, depending somewhat on the character of sewage and the manner of operating the beds. Obviously, if the beds retain the sewage in the absence of air for a sufficiently long time aerobic action will cease and anaerobic decomposition will begin.

American Experience.—So far as known there is no practical experience in America in the operation of slate beds, although as Mr. Clark states they originated at Lawrence, several years before they were studied by Mr. Dibden. They have been studied at Lawrence since 1901 with results summarized on page 301 of the 1901 report, on page 413 of the 1908 report and on page 250 of the 1910 report of the Massachusetts State Board of Health. The evidence on the whole is not very promising as to these devices as clarifying arrangements, and the results are indecisive both as to value of the sludge digestion and the cost of this treatment in comparison with other arrangements doing approximately the same amount of work.

At the Philadelphia testing station, as stated in the 1911 report, tests with slate beds were made in a tank 5 feet deep containing 19 horizontal layers of 12 by 24-inch slates separated by brickbats to give a space of 3 inches between them. The best results were obtained when the bed was filled and drained slowly twice a day at a rate of about 2 million gallons per acre daily. The removal of suspended matter varied, but averaged about 75 per cent. The effluent was slightly nitrified. The deposit on the slates was inodorous, resembling earth, and could be removed by flushing in a small sized bed, although deposits away from the flushing exits accumulated to a depth of 1 inch.

HAMPTON DOCTRINE

The various strainers and roughing filters above described have for their especial purpose the removal of floating or settling solids or both. Incidentally there will presumably be some removal of non-settling solids, particularly if fairly fine material with a moderate rate of flow is employed.

In the early days of the so-called biological processes it was believed that when sewage was applied to the filters there was a direct consumption of various organic matters by micro-organisms, particularly the bacteria. The physical side was considered an incidental part of the process, and within certain limits the same may be said of direct chemical purification by means of oxidation.

Dr. Dunbar showed about 1900 that in well operated filters there is a speedy chemical oxidation or conversion of organic matter into relatively stable compounds through absorption and other changes occurring upon and within the slimy coating which attaches itself to particles of filtering material. Mr. Bretschneider, of Charlottenburg, Germany, provoked considerable discussion in 1905 through his suggestion that sewage purification was accomplished largely through physical or mechanical means, and that biological developments are mere incidents to the process.

Dr. W. O. Travis, of Hampton, England, in association with Mr. J. H. Johnston and others, has contributed a highly important series of papers on the theory of sewage purification. These views are frequently spoken of as the "Hampton Doctrine." They elaborate upon the importance of the physical side of sewage purification in particular reference to the non-settling and colloidal matters, and the separation thereof from the liquid sewage by a process which Dr. Travis calls de-solution.

In the opinion of the author the work of Dr. Travis is of much importance. Unfortunately the matter has become the subject of considerable controversy and has led various scientists to dwell on certain aspects of this complicated series of phenomena, to the exclusion of others. We will not attempt to detail the relative merits of the physical, chemical, and biological aspects of sewage purification. Reference is made to various writings of Dr. Travis, particularly as found in *The Surveyor* of Dec. 18 and 25, 1908; Jan. 1, 1909, and Dec. 15, 1911. We quote a few paragraphs to show the scope of the doctrine as follows:

> The Hampton researches, therefore, have shown that the removal of the colloids in pseudo-solution from the sewage, and, indeed, of all the other impurities, whether suspended, soluble, or volatile, are the effects of the physical operations, in contradistinction to those of a vital nature. They have also demonstrated that the great desideratum in sewage purification processes is the improvement of the mechanism, or as

stated in 1905 by T. Hughes, in his admirable and practical paper "A Retrospect of Six Years' Treatment of Crude Sewage in Triple Contact Beds, and a Forecast," "the perfecting of the means for the removal from the sewage of these several matters, solids in suspension and solids in emulsion."

The physical arrestment of the obvious suspended solids by deposition, and by straining, as well as by attraction, and by adhesion to the surfaces of material, and to their slimy coating, is not disputed by anyone; it is admitted in the Dunbar absorption theory and by the Hampton doctrine. The removal of these matters, and their subsequent history, which is equally well known, do not require further elucidation. For they are "mechanically arrested," they become "a burden upon the filters," their dissolution "is very slow," and "there is always a large irreducible residuum."

It is far otherwise with regard to the remaining constituents of the sewage, and it was in reference to these matters, as well as to the operations attending them, that there was alleged to be a "divergence of practical experience from theoretical representation." It is here that precise experimental investigations are urgently needed, in order that light should be thrown upon this abstruse part of the problem. The questions awaiting final decision are: How are the soluble and pseudo-soluble constituents of the sewage removed from that liquid? How are they converted? And what remainder results from the operations in artificial treatment areas?

The divergence above referred to can be exemplified by the fact that if the above questions were submitted to a number of authorities, even to those who have made the most profound study of the subject, they would elicit answers of the most varied character, all of which could not be right and in strict accord with the practical operation.

These several views may be classified as follows:

(1) *The theory that the dissolved and the pseudo-dissolved solids are not removed from the sewage by any preliminary operation, but are directly and completely oxidized.* The change being effected during the transit of the liquid through the treatment area. This view has been very extensively held in the past, and while it would be invidious, if not difficult, to attach a personal name or names to it, the honor even might be disputed, it is necessary to adduce an authority, for the purposes of identification and corroboration. The City of Leeds Report (1905), which is selected because the experiments were of a public character, and also because it was referred to in the contribution, states that "the action of the oxidizing bacteria of a percolating filter on dissolved impurities is striking rapid," and infers that the conversion occurred "in 3 minutes"—*i. e.*, in the time taken for the sewage, as determined by a fluorescine solution, to pass through the filter.

(2) *The Dunbar absorption theory*, which alleges that the dissolved and "the pseudo-dissolved constituents in sewage are absorbed, and that the material thus blocking up the slimy coating is decomposed during the period of rest between two separate charges, by condensed oxygen, enzymes, microorganisms, etc., so that the products of decomposition may be taken up by the next charge of sewage in exchange for its putrescible matters"; and

(3) *The Hampton doctrine*, which supports the Dunbar absorption theory in holding that the impurities are removed from the sewage, as a preliminary physical effect, but which differs from that theory in holding that the *property of retention* plays an equally important part in sewage purification processes, and is also at variance with it in teaching the necessity for differentiating between the operations upon the solids in actual solution, and those upon the solids in colloidal solution. The soluble solids being mainly removed by a process of absorption, the tendency of which is towards saturation, or to the establishment of an equilibrium, an effect which would be speedily brought about in artificial treatment areas, unless counteracting forces were at work, removing or destroying the absorbed matters. This action, therefore, is strictly dependent upon the renovation of the absorbing surface for its effective continuance. Whereas the pseudo-dissolved solids are deposited in the filter as solid matter, which, instead of demanding immediate destruction, in order to insure the deposition of the putrescible matters in the next charge of sewage, remains in the filter, increases, indeed, largely forms, the absorbing area, and in this way tends to the more efficient action thereof. Moreover, this depositing operation will continue, uninterruptedly, and, *ceteris paribus*, more and more completely until the filter is choked.

It would have been especially useful if the recently-issued Fifth Report of the Royal Commission on Sewage Disposal had made some authoritative announcement, which could have been adduced at the present juncture. Unfortunately, however, there is little which can be regarded as bearing this character, though the following quotation has some reference to the subject under discussion, and is not without interest:

"The generally accepted theory as regards nitrogenous matter seems to be that the ammonia is extracted from the liquid during the period of contact, and oxidized during the period of rest, and that the resulting nitrate and nitrite are diffused through the liquid of a subsequent filling. All the ammoniacal nitrogen, however, does not appear in the effluent in the oxidized state, for there is always loss of nitrogen, as nitrogen gas during the process."

"The withdrawal of suspended and colloidal matter from the sewage during its passage through the bed appears not to be a simple mechanical effect of the material, for a matured contact bed, not clogged, will with-

draw more suspended matter from the sewage than another bed similar in all other respects, but not matured."

The Royal Commission, in giving expression to the beliefs that "the ammonia is extracted from the liquid during the period of contact," and that the suspended and colloidal matters are withdrawn "from the sewage during its transit through the bed," supports the second and the third of the enunciated views in holding that the impurities are removed by preliminary physical operations; and repudiates the theory that the dissolved impurities are oxidized during the transit of the sewage through the treatment area, so that nothing further remains to be said in regard to this view. Further, in separately considering the ammonia, and in associating the colloidal matter with the solids in suspension, the report exhibits indications, if nothing more, in favor of the last stated theory . . . . .

The Hampton researches had demonstrated, experimentally and practically, that surface action played a highly important part in the removal of the sewage colloids. They had also determined that sterilization did not prevent ultimate de-solution. These facts, however, did not justify the observers in stating more than that the solids in colloidal solution were deposited in virtue of a physical operation. Indeed, in a complex liquid like sewage of varying constitution, and containing a variety of colloids, it is by no means improbable that other forces are engaged; for instance, oppositely charged colloids, the presence or development of electrolytes, the interference with the electric charges of the particles, etc., and that there may be found to be a modification of the phenomena in different sewages. Whether this be so or not, the removal of colloids from their condition of solution has been abundantly demonstrated to be the result of a coagulation of the colloid particles, and in so far as the examples given above belong to the same class they can be demonstrated to be removed in the same way. Draper has shown that the phenomena of the dyeing process are identical with the de-solution phenomena of colloids. He holds, with Krafft, that the process of dyeing consists, in the majority of cases, in the separation of colloidal salts on or in the fiber. He argues that the colloid molecules are in a state of unstable equilibrium, and that, under the influence of a "porous fiber substance," aggregation occurs to such an extent that they are thrown out of solution on the fiber and adhere to it by mutual attraction. Linder and Picton support this view, and regard "dyeing as a phase of coagulation." Bechhold has shown that enzymes and toxins have a tendency not shared by ordinary albuminoids to combine with or "dye" filtering material, specially prepared to separate the colloidal particles from their "solvent." Biltz and Kröhnke have stated that these various substances are now treated from the aspect of colloid chemistry, and that the term "absorption" is no longer used

in regard to them, "adsorption" being employed instead. The terminology, however, is immaterial. The effect is of moment, and this is expressed as solid matter . . . . .

Here is a typical illustration of the divergence between theory and practice. For if there is one fact more than another which practical experience has demonstrated it is the large amount of sludge accumulation in filters and in beds. Three years ago it was stated that: "It may be convenient to touch lightly upon this subject of retained solids, and to speak of them as inoffensive and innocuous matters akin to humus or garden soil, but it is wiser to describe these solids as they are. The term 'humus' is deceptive. The sludge which passes on to a bed is rich in organic nitrogen; that which is retained therein and that which is carried through are equally rich; all are sludge, and all abound with microorganisms." Since this was written numerous sections of the contact beds have been taken, the removed material has been washed, and the resulting liquid analyzed. The entire contents of ten contact beds have been removed, and washed, one-half of them on two occasions; the resulting sludge was regularly submitted to analysis. The nature of the solids issuing from each of the contact beds has repeatedly been chemically determined. Finally, the material in the experimental percolating filter, and the granular matter coming from each of the compartments have on many occasions been analyzed, and it has not been possible to say that any one of the large number of samples examined, especially when the solids were removed from their associated liquid, was non-putrescible. It was intended to elaborate this statement, but it has been rendered unnecessary, because the observations have been confirmed by the Fifth Report of the Royal Commission on Sewage Disposal, which states, in regard to the suspended solids in effluents, that: "As is well known, these suspended solids are always—or practically always—putrescible. Indeed, we cannot recall any instance in our own experience in which such solids, when examined apart from the liquid portion of the effluent, were non-putrescible . . . The results show that the suspended solids from biological sewage filters, whether contact beds or percolating filters, are in themselves putrescible, and that they are capable of taking up oxygen from water comparatively rapidly. So long as such solids are kept moving in oxygenated water, or in water containing nitrate in solution, they will not give rise to nuisance from smell, but if allowed to accumulate in the sluggish reaches of a stream, they will ultimately form black and putrid mud, which will draw upon the oxygen in the supernatant water; if present in very large quantity they will, in those circumstances, give rise to objectionable conditions . . . . .

"The filter had thus evacuated nearly twice as much suspended matter as had entered it, and had conclusively demonstrated the truth

of the aforementioned hypothesis, 'that matters which were not recorded as suspended in the applied sewage became so in the beds,' for they had in large part found expression as suspended matter in the effluent. The source of the additional suspended matter was also clearly determined, for of the 22.5 parts colloids which had entered the filter 11.0 were uncoagulated and were determined as colloids in the effluent, while the remaining 11.5 parts were flocculated and deposited in the beds."

While the author does not share fully with Dr. Travis the views expressed as to the relative lack of importance of the chemical and biological aspects, he agrees that the physical side of the question was for years neglected and that true progress has recently resulted in a substantial measure from a clearer appreciation than hitherto of the great importance of the physical side of the question.

Some of the increase in suspended matters in the effluent as compared with the influent of coarse-grained filters is explained at times by the presence of dead or living organisms which have fed on soluble as well as colloidal matters.

With regard to the influence of suspended matters upon the stability of sewage, it is of interest here to refer to the observations recorded by Dr. Lederer, of Chicago, in his Havana paper. As stated in the *Engineering Record* of Dec. 23, 1911, he found that after removing the suspended matters through filter paper the effluent was five times as stable as was the unfiltered sewage when measured by the rate of deoxygenation of water by the Phelps method. This observation points clearly to the support of the Hampton theory in that it is highly important to de-solve colloidal matters from sewage. To what extent the results of Dr. Lederer's observations are representative of sewages in general we do not know.

COLLOIDORS

While believing that Dr. Travis has done much to promote a better understanding of sewage purification and filtration, the author is in doubt as to what extent this information may be availed of in practice. Assuming that colloidal and finely suspended sewage matters should be thrown out of solution as a preparatory step to filtration, the question then arises, How is de-solution to be effected in practice so as to give better results than now obtained with sedimentation and filtration?

Colloidors are devices by which an attempt is made by Dr. Travis and his associates to remove non-settling solids from sewage. These devices are practically a series of wooden splines about one square inch in cross-section and hung vertically in the central portion three-fourths of the length of the sedimentation chamber of two-story tanks of the Travis type. These wooden strips, as shown in Fig. 47, are placed about 3 inches apart transversely and from 5 to 9 inches longitudinally. These colloidors or colloid collectors have for their function the attraction of fine non-settling suspended solids and thus permit the coalescence or coagulation of some of the colloidal matters.

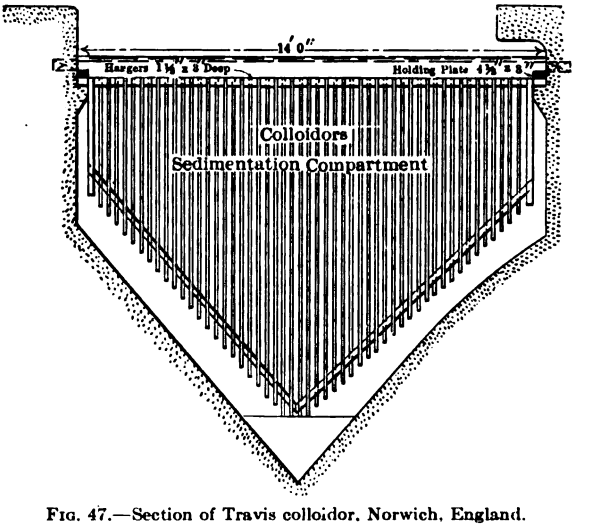


FIG. 47.—Section of Travis colloidor, Norwich, England.

After the sewage has flowed through the upper compartment of a two-story tank of the Travis type it then passes through a hydrolyzing chamber. This chamber holds about 4 hours' flow, and in it are placed numerous colloidors except at the bottom, where space is left for the accumulation of sludge. The above figure is taken from a paper by Mr. Arthur E. Collins descriptive of the Travis hydrolytic system constructed at Norwich, England. Full details may be found on page 261 of the *Journal of the Royal Sanitary Institute*, Vol. XXX, 1909. An abstract of the paper is also to be found in the *Engineering Record* of July 25, 1908.

Mr. Saville states in his Boston paper of December, 1910, that he found objectionable odors at the Norwich plant. This is due

evidently to the bacterial decomposition of arrested suspended matters which come in contact with the flowing sewage. To what extent it may be possible to secure the advantages of desolution without the disadvantages of anaerobic decomposition with attendant odors is a question that we cannot now answer. It is an important subject for further study.

MECHANICAL FILTRATION

In connection with studies of the Baltimore project the author made the suggestion early in 1906 that the effluent of sprinkling filters might be further purified with the aid of coagulation and rapid filtration through sand filters, more or less resembling the well-known mechanical filters used in water purification. This suggestion was predicated on a few laboratory tests at Columbus as to the amount of coagulation necessary to free these liquids of the finely divided particles unresponsive to subsidence; and, further, that the amount of coagulant would approximate that required for equivalent amounts of turbidity in clay-bearing waters after plain sedimentation.

This matter has been studied by Mr. Clark, of Lawrence, at some length. Results have not been promising, as stated by him on page 229 of the 1907 Report of the Massachusetts State Board of Health. To the settled effluents studied he found that is was necessary to apply about eight grains of ferrous sulphate and 10 grains of lime per gallon in order to produce a clear effluent. The filter was operated at the rate of about 50 million gallons per acre daily, and it was necessary to wash the filter at intervals of about 4 hours. The expense of chemical is given as $10.30 per million gallons. The comparatively poor bacterial results and the cost of washing the filters showed that the method as there applied had small value among sewage disposal schemes in accordance with the data given. Using sulphate of alumina as a coagulant, however, it was found that as good an effluent could be produced at less than half the cost and the yield of clean water between washings was about doubled. For the purpose for which the method was suggested there is no doubt about this treatment being decidedly inferior to sterilization with hypochlorites. It is mentioned here to indicate a means of removing non-settling solids and colloids with considerable thoroughness, although it is not intended to convey the impression that the

removal of these matters in this way would be of sufficient aid in ordinary sewage purification projects to justify their cost. We know of no data which would indicate the worth of such treatment, as measured by the aid which it would afford to either sand filters, contact filters or sprinkling filters.

RÉSUMÉ

Strainers and roughing filters either with or without the aid of enforced aeration do not seem to be practical arrangements for the clarification of raw sewage. Sedimentation is cheaper and better.

Roughing filters, as adopted for two purification plants at Atlanta, are doubtless capable of retaining floating matters which escape from sedimentation tanks. They are also capable perhaps of providing some further clarification of the settled sewage before it reaches the sprinkling filters. Such devices must be carefully washed; otherwise they may unload suspended matters and produce clogging both at the filter surface and at the sprinkler nozzles.

Roughing filters for this service will meet competition in fine screens, such as are being installed at one of the sprinkling filter plants at Atlanta and at the large works at Baltimore. It will require data from actual operations to make a choice between these two arrangements.

With respect to the Hampton Doctrine on the importance of freeing sewage so far as practicable of suspended and colloidal matter, the indications are that there is much to support the correctness of this important deduction of Dr. Travis and his associates. Unfortunately controversies have tended to accentuate one feature of sewage purification to the exclusion of another. De-solution of non-settling suspended and colloidal matters in sewage preparatory to filtration seems helpful to the limits to which it is practicable to carry it. What that limit actually is cannot now be stated. Practical developments hitherto have not been very successful. Chemical precipitation removes some of the colloids but at a high cost. It remains for the future to show whether it is better to have de-solution occur in filters as at present or to provide a preliminary treatment for the economical removal of finely divided suspended particles and colloidal substances in sewage without encountering the disadvantages attending anaerobic decomposition.

It is certain that it is helpful to treat sewage while it is fresh and before suspended matters become comminuted to the non-settling and colloidal state.

The slate beds of Mr. Dibden represent correct practice as to keeping sludge treatment on an aerobic basis, and under favorable conditions it appears that the sludge may be well treated in this way. Its practicability is associated with questions of economy as compared with other devices doing equivalent work. Cost data are now meager.

CHAPTER XVIII

BROAD IRRIGATION

"Broad irrigation," "sewage farming" and "land treatment" are names used for the process by which sewage is applied intermittently to land at a rate so low that it does not interfere with the raising and harvesting of crops.

In a more or less irregular way this method of sewage disposal has been practiced at some places abroad for centuries. Forty or fifty years ago it received a decided impetus in England, where it was favorably commended by a royal commission as a proper means of relieving certain rivers of pollution, which at that time had become excessive. For more than a generation in England, land treatment was considered one of the principal means of sewage disposal. In fact, chemical precipitation was the only method which competed with it up to the establishment of the so-called modern biological processes. Even the Local Government Board, having the control over funds expended by the local authorities, maintained stoutly its position of requiring land treatment. This led in 1898 to the appointment of the Royal Sewage Disposal Commission of Great Britain. After several years of consideration the latter concluded that filters of artificial construction with proper safeguards could be relied upon to purify sewage without broad irrigation. The valuable reports of this Commission shed much light upon what these safeguards should be.

The popularity of broad irrigation in England spread to the continent and, while experience was obtained on a large scale at many British plants, the subject was carefully investigated at several important continental cities. At Paris in particular was the matter studied from the chemical standpoint beginning in 1868 with a series of tests at Gennevilliers, first by Mille and later by Durand-Claye. In Germany the question was studied carefully under the leadership of Rudolph Virchow and portions of the important Berlin sewage farms were put in service in 1876.

This subject is discussed in considerable detail by Messrs. Rafter and Baker in their book on "Sewage Disposal in the

United States." Later information is given by Mr. Rafter in several publications, particularly Water Supply and Irrigation Papers Nos. 3 and 22 of the United States Geological Survey. Mr. Baker also makes instructive comments on sewage farming abroad in "British Sewage Works," published in 1904, just as the Royal Commission suggested modifications in the practice of the Local Government Board to insist upon land treatment in all cases.

EXTENT OF USE

In 1904 the author found that in the United States there were then in service some 14 municipal sewage farming or broad irrigation projects serving a population estimated at 200,000 people. There were probably also a number of institutional plants of some size still in service. This method was first applied in the United States at the State Insane Asylum near Augusta, Maine, in 1876.

Strictly speaking, this method is not in general use in this country except in the Far West, although there are some intermittent sand filter plants in the East where crops are raised on portions of the area. Some profit results from the use of these filter areas for agricultural purposes, but this seems to be a small and incidental feature. There appears to be no good reason, in the opinion of some, why crops should not yield in the East a sufficient revenue in some cases to cover perhaps the cost of caring for the plant, and even in some instances to provide some interest on the investment. So far as known, this has rarely if ever been the case.

Broad irrigation in the East is rendered less advantageous by the heavy rainfalls which occur quite frequently during the late summer and early autumn, and which are likely to result either in the discharge of raw sewage into some neighboring brook, or in the application of such large doses to the rain-saturated filter beds that the crops are seriously injured, especially at times of harvesting. Consequently, at most of the eastern plants, crops are raised only on a portion of the filter areas, if at all.

In the Far West, where the rainfall is very small on an average (12 to 15 inches per annum), and confined to a small portion of the year (two to four months), irrigation with either water or sewage is quite essential for the success of many agricultural

pursuits. Sewage is used for purposes of irrigation with some success at a number of places in that section, but the sanitary question of disposing of the sewage seems to be quite incidental.

The crops raised on sewage farms include nearly all those ordinarily attempted in the section where the plant is located. Among them may be mentioned peas, beans, tomatoes, corn, cabbages, turnips, grass, alfalfa, various fruit trees, etc. In some instances a popular prejudice against vegetables raised on sewage farms has been encountered.

Available evidence does not indicate that sewage irrigation is making substantial progress in the arid districts of America. On the contrary, the process seems to be decidedly on the wane and almost without accredited standing if attention is given to instances where proper observance is made of sanitary requirements.

One of the earliest examples of sewage farming was at Pullman, Illinois. The soil is rather impervious and unsanitary conditions arose, as described by Messrs. Rafter and Baker, so that when the town was annexed to the city of Chicago sewage farming was abandoned. At Los Angeles sewage farming to a limited extent was practised some years ago, but since the completion of the new outfall to the Pacific ocean in 1905 the practice has been abandoned. This is due largely to the rapid growth of the city and suburbs in the direction of the ocean and the desire of property owners to sub-divide into house lots what was once irrigable land. According to Mr. Willis T. Knowlton another reason is found in the fact that the health authorities have been appealed to by property owners, who object to the odor from sewage farms.

At Pasadena, California, irrigation with sewage is still in use on a city farm of some 460 acres, of which 300 acres were purchased by the city in 1887 and the remainder in 1904. As the population both of the city and its suburbs has increased, trouble has been encountered with smells, and as stated by Mr. Knowlton the Pasadena sewage farm is likely to have a somewhat similar ending to that of the farming areas along the old Los Angeles outfall sewer. In 1910 a septic tank was completed to free the sewage of some of the solid matters, in hopes of minimizing odors from the irrigated areas, which are devoted to a considerable extent to the growth of walnut trees. Objection still continued on the part of the property owners in the neighboring town of Alhambra, and in the autumn of 1911 investigation was made

of electrolytic devices such as used at Santa Monica. It is said that the test was not successful. Prof. C. C. Williams, in the *Engineering Record* of Feb. 24, 1912, states that it has been decided to irrigate the Pasadena farm with clear water beginning in 1914. It is also stated by Mr. Knowlton that some discussion has been given to a joint trunk sewer to the Pacific ocean to serve the three cities of Pasadena, South Pasadena and Alhambra; and also that Mr. Van Ornum, City Engineer of Pasadena, has given study to treatment works embodying sedimentation and filtration.

Many references in technical journals can be found to the use in the West of broad irrigation as a means of sewage disposal. But the facts usually show that such use was merely incidental and not entitled to serious consideration from the sanitary standpoint. Thus Prof. Williams points out that Colorado Springs did not employ broad irrigation systematically, but has discharged practically all of its sewage in a raw state into Fountain creek. At Greeley, Colorado, Prof. Williams also states that the sewage flow is rented to a man who uses it only during the summer season for truck farming, while during the remainder of the year it is discharged without treatment into Cache la Poudre river.

Salt Lake City, Utah, has a sewage farm which was said in 1904 to have an area of 150 acres. The sewage flow was stated in 1908 in the Annual Report of Mr. L. C. Kelsey, City Engineer, to have then reached 21 cubic feet per second. The same report shows that the sewage farm, evidently including the right to use the sewage flow, was rented for a term of five years in 1907 for annual payments amounting to $50., $75., $150., $200., and $250., respectively. Prof. Williams also states that the sewage flow in 1911 was 43 cubic feet per second, and adds that the city has had difficulty in extending the outlet sufficiently to allow all of its sewage to be used to advantage.

At Fresno, California, a broad irrigation plant or sewage farm was installed in 1907, according to an article in the *Engineering Record* of Aug. 22, 1908. The area purchased by the city comprised 812 acres and a septic tank was built under the direction of Mr. George L. Hoxie, City Engineer, to purify the sewage before its application to the farm. The bond issue was for $175,000, of which apparently $37,000. were used for improvements within the city. The schedule of rentals begins with

$2000 on Nov. 15, 1911, and calls for $9000 for each year thereafter.

Taking the evidence as a whole, it is safe to say that even in the arid regions the general outlook is clearly toward a decrease rather than an increase in the systematic practice of broad irrigation. In fact, it appears that there is now scarcely a plant in which satisfactory sanitary results are uniformly secured.

HYGIENIC ASPECTS

Quality of Effluent.—Under favorable conditions the sewage which is filtered through the material of a sewage farm represents the highest degree of purity that it is feasible to obtain. Literally it produces "spring water." We shall not attempt here to enter into the question of chemical and biological purification, but simply will state that, at the low rate of filtration which is used, this process produces even better results than those obtained with intermittent filtration, as discussed in detail in Chapter XIX.

Bypassing.—From what has been said above it is plain that sewage filtration, with its high quality of effluent, seems to be an incidental feature to broad irrigation as practised at nearly all places in this country. When the sewage is not considered helpful for agricultural uses there is altogether too great a tendency to divert it to some neighboring stream bed. This difficulty has been regulated properly in some of the large European plants, but it requires the constant and careful effort of a competent corps of inspectors and patrolmen. Otherwise the sanitary requirements as to sewage disposal become entirely subservient to the interest and convenience of the farmer.

Raw Vegetable Question.—There is a decided prejudice in some places in America to the use of sewage on farms devoted to the production of vegetables which are eaten in a raw condition. The available evidence does not show many specific instances of such trouble, so far as known to the author, yet the point is certainly well taken in the interests of the public health. On sewage farms there should not be grown for human consumption any vegetables which are eaten even occasionally in a raw condition. There is no reason why this should be done, as various trees and other crops may be grown that are related in no immediate way to the public health.

Fly Question.—Within the past few years there has developed in some localities apprehension as to the transmission of disease germs by flies or other insects even to locations considerably removed from sewage farms upon which fecal matters are exposed. It is not at all unlikely that in some instances this is based on fair assumptions, where opportunity is afforded for flies to come in contact with disease germs of intestinal origin. In this way the sewage farm bears some resemblance to the privy vault, which is rightfully considered a menace to health in the absence of effective screening.

While the evidence shows that broad irrigation may afford excellent purification of sewage, the hygienic aspects on the whole are disappointing. Health ordinances alone will not correct them. If broad irrigation were to be adopted in fulfillment of rigid sanitary requirements, it would have to be practised under conditions far more careful than has been the case hitherto in any instance with which we are familiar in America. It has been said by some that this method might be employed in conjunction with other processes, thus allowing benefit to be derived from the broad irrigation method. This does not seem to be a practical suggestion under ordinary financial conditions, as the alternate method is likely to prove to be more efficient and economical. There may be exceptions to this rule.

FINANCIAL ASPECTS

Suitable Site.—Suitably isolated sites are difficult to obtain in the vicinity of some towns and cities, particularly if reasonable allowance is made for the growth of the community during a term of years. It means that the works for conveying the sewage to what might be called a reasonably permanent site assumes large figures. In fact, in 1908 the author found that at El Paso, Texas, it would cost more to convey the sewage to a suitably isolated site for a sewage farm than it would to establish other types of disposal works not far from the outskirts of the city.

Soil and Climatic Conditions.—These features are of much importance. In northern climates, where the winters are long and severe, with a normal penetration of frost of from 3 to 7 feet, the feasibility of this method depends much upon having a porous soil with which to work. Otherwise it means either

storage of sewage in some kind of basins of cheap construction or alternate methods of sewage treatment or diversion to a neighboring stream bed. In the arid regions of the Southwest the effect of soil is also of importance, although frost is not a complication. During the growing season there is usually but little rainfall, but there are times even in the arid regions when rains appear during the harvesting season in a way to produce interference with sewage treatment, unless there are reserve areas to utilize on such occasions. Upon large sewage farms that are carefully managed the rotation of sewage over different sections devoted to different crops may minimize the influence of this complication. With small farms that are not closely inspected it seems difficult to prevent the sewage from being diverted from or misapplied to land that is not porous. Not only have the operators of these farms to reckon with the interference of sewage treatment during their harvesting operations, but where the material is fine they also have to face a contingency of clogged surfaces with putrefying pools of sewage and their attendant bad odors.

Comparative Duty.—Prof. Williams in his statement in the *Engineering Record* of Feb. 24, 1912, says that broad irrigation is wasteful of water in arid regions, and that with few exceptions the irrigating duty of the sewage is reduced as compared with what would be obtained with clear water. He states that raw sewage seldom serves more than one-third to one-half as much area as the same quantity of clear water or well filtered sewage. This is largely due to the surface clogging of the soil by the solids in the sewage. It brings to mind the "sewage sick" lands of European farms that are overdosed. When the surface of the soil becomes clogged so that pools of sewage are formed it is difficult to prevent objectionable smells. It was the odors from clogged filter surfaces that caused the abandonment some years ago of the sand filters at Plainfield, N. J., where crops were raised only in an incidental way. From a financial aspect it means that where water is scarcer than land, raw sewage so reduces the duty or irrigating power of the liquid that it constitutes a serious drawback to the method.

Irrigating Value.—In the arid districts there is opportunity for more favorable financial returns from this method than elsewhere because the sewage saves the cost of water for irrigation. The right to use all the water needed for irrigating purposes,

in perpetuity, is stated to have a value averaging perhaps $75 per acre, although it varies much in different localities. The interest on this sum, say $4.50 per annum, gives a rough measure of the value of irrigating water used per annum for one acre. On an average the volume of water used during the irrigating season for each acre amounts to say 0.0125 of a cubic foot per second, or about 8000 gallons per day. On this basis the annual sewage flow to one acre would amount to 2.92 million gallons. This means a value of about $1.50 for one million gallons of sewage, and with it is the obligation to treat the sewage satisfactorily for months at a time when it is not needed for irrigation.

The above sum is insufficient for many if not most cities to deliver the sewage to tracts suitable for sewage farming. It is true that the above assumptions as to the irrigating duty of water, 1 cubic foot per second for 80 acres, is less favorable than shown in many cases; but it is believed to be a fair figure for general irrigation practice in many western States. The worth of such water rights also varies widely. Many sales have been made at a lower figure than the above in the case of large gravity projects, but where the water has to be pumped or obtained from far distant sources the worth may be much in excess of this figure. However, enough has been said to show that sewage for irrigating purposes does not offer hopes of great financial returns to the ordinary city in the arid regions.

Manurial Value.—This question has been studied by agricultural chemists for several generations. The theoretical figures vary widely for different sewages and for fluctuating prices for nitrogen, potash and phosphates, which are the principal fertilizing elements in sewage. The subject is well reviewed by Messrs. Rafter and Baker in their book, pages 158–62. Mr. Rafter also speaks of this subject in Water Supply and Irrigation Paper No. 3, page 23. He concludes that when sewage is applied to good advantage in agricultural utilization it may have a theoretical value of one to two and perhaps three cents per net ton. In one million gallons of sewage there are 4167 tons. On the above basis this means that one million gallons of sewage under the most favorable circumstances might have a theoretical value ranging from about $42 to $125. If sewage were regularly applied at the ordinary average rate at which water is used for irrigation there would be about 3 million gallons added to one acre per year. The figures of value above stated would then have

to be multiplied by three in order to obtain the theoretical worth of the potash, phosphates and nitrogen in the sewage added to one acre annually.

The above comments and data show that there are wide differences between theory and practice on this question. The sums above stated are, of course, far in excess of those ordinarily required for the application of artificial fertilizers. How far sewage is of practical fertilizing value is a matter upon which we are not informed. Some of the constituents may be only partially available for manurial purposes. They may pass quickly with the effluent beyond the reach of growing crops. Others may be retained at or near the surface under conditions where they are of only limited value. Still again it is to be pointed out that when sewage, with its enormous dilution of fertilizing elements, is applied to land as a regular procedure its value as a fertilizer may become practically *nil.* Reference is made to the bibliography quoted by Messrs. Rafter and Baker. In the *Engineering Record* of Nov. 24, 1910, Prof. J. A. Voelcker, Consulting Chemist to the Royal Agricultural Society of England, states in a paper that "the manurial value of sewage, as it is now generally met with, and whether it be in the form of crude sewage, of sewage deprived of its solid matters, or of sewage sludge, is but very small."

Nitrogen is the most valuable element in sewage as a fertilizer. In connection with its removal from the soil and its appearance in the effluent as nitrates, attention should be given to the comparative cost of other means of securing nitrogen. Among other ways mention may be made of the custom of enriching the soil by plowing in such crops as field pease, alfalfa, clover, etc.

From the earliest times the utilization of sewage for its manurial value has been an attractive subject for numerous writers. Perhaps no one has stated it in more glowing terms than Victor Hugo, whose views are quoted in the *Engineering Record* of Jan. 20, 1912, page 82, in a letter addressed to the editor by Mr. P. A. Maignen. Vegetation is somewhat promoted through the use of sewage. Whether such use is worth while is a very doubtful question.

CAPACITY

Broad irrigation usually provides for the disposal of sewage under advantageous circumstances to the extent of from about

3000 to 12,000 gallons per acre daily on an average. It depends much upon conditions of soil and climate for any particular project. Perhaps 100 persons connected with the sewers for each acre of land is as fair a figure as can be given as to the ordinary loading. With clay soils serious surface clogging may result when the load is one-fifth or even one-tenth of this figure. On the other hand, where the material is porous, the rates and loads may be materially increased. In fact, they reach proportions similar to those experienced with intermittent sand filters, as described in the next chapter.

The capacity of irrigation areas may be substantially increased if solid matters are first removed from the sewage as is the case to a considerable extent at Paris. At Berlin more attention is being given to this feature and aid is also received from storage basins and the use of high rates which at times appear to reach 50,000 gallons per acre daily.

In a recent report by the Metropolitan Sewerage Commission of New York City, as stated in Chapter X, estimates were made on the application of sewage to the fairly sandy soil of Long Island at an average rate of 12,000 gallons per acre daily.

EUROPEAN EXPERIENCES

While broad irrigation is not likely to receive wide attention in America, it is nevertheless a fact that the well known sewage farms of Paris and Berlin attract much attention and reference frequently is made to them as to efficiency, economy and the satisfactory way of utilizing the sewage. It is thought well to refer to these projects, particularly as to their extent and cost.

PARIS SEWAGE FARMS

The Paris sewage farms are well described in a paper sent to the International Engineering Congress at St. Louis, Mo., in 1904, by M. Bechmann, at that time City Engineer of Paris. This paper, reviewing progress in sewage disposal in France from 1894 to 1904, was translated from the French by the author. It appears in the *Transactions of the American Society of Civil Engineers*, Vol. LIV, Part E, page 195. The following account of the means which Paris adopted of freeing the river Seine of gross nuisances is taken from the translation above mentioned.

Fig. 48 is a sketch map from one of M. Bechmann's reports, showing the general location of the Paris sewage farms.

Situation in 1894.—In 1894 only one French city, Rheims (population about 100,000), was able to claim that it treated all of its sewage effectively. In this instance the sewage was conducted, partly by gravity and partly by pumping, a short distance from the city limits to a purification field, where a thin layer of earth overlies fissured limestone. It was distributed under pressure in a piping system, suitably equipped with regulating valves, etc., to trenches, largely made by plowing. The rate of application was not more than 30,000 cubic meters per hectare

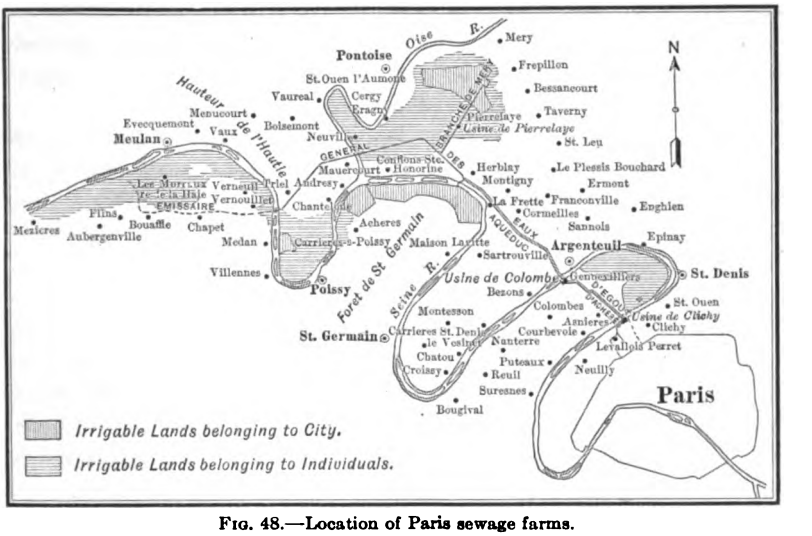


FIG. 48.—Location of Paris sewage farms.

per year (equal to about 3,200,000 U. S. gallons per acre annually. or an average daily quantity of about 9000 gallons per acre), The sewage was not only purified in the porous soil, but at the same time served for the fertilization of an agricultural area conceded by the city to a company, and enlarged by the latter. This concession was made with the proviso that, to prevent all contamination, the sewage should not reach the watercourse which drains the region, the Vesle, until after its purification.

This was the first systematic application of the process advocated since 1864 by Mille and later by Alfred Durand-Claye for the city of Paris, and which since 1868 has been the object of

notable investigations and results at Gennevilliers. Notwithstanding the favor with which the agriculturists of this region, after their first opposition, welcomed finally the use of sewage for their farms, which they have little by little extended since 1872 to nearly 900 hectares (2225 acres); notwithstanding the complete purification of the sewage thus treated and rendered not only inoffensive but so free from organic matter, ammonia and bacteria as to be fresh, limpid and practically potable; and notwithstanding the persistent efforts of the city of Paris and the support of the Board of Public Works, the passage of a law, by the Chamber of Deputies and the Senate, in 1889, to permit an extension of the system to the area at Acheres, on the border of the forest of Saint-Germain, was obtained with great difficulty. The works undertaken by virtue of this law, not having been completed, public opinion remained hostile, and circumstances were but slightly favorable to new methods.

Purification by Irrigation since 1894.—The extension of the irrigation works for the treatment of Paris sewage upon the area of Acheres (800 hectares, or nearly 2000 acres), undertaken under the law of July 10, 1889, was completed in 1895. This, however, was only a step toward the final solution of the problem, since the new purification field, as in the case of that at Gennevilliers, is only able to receive the quantity authorized by law, which is 40,000 cubic meters per hectare per year, or 4,280,000 U. S. gallons per acre per year, equal to 11,800 U. S. gallons per acre daily on an average. This was only a fraction of the total sewage flow, and the greater portion still continued to discharge into the Seine. All of these additions, however, were designed by the municipal service to be of such proportions that they could later be utilized satisfactorily with the further extensions to be undertaken in connection with the "purification of the Seine," which had for its ultimate object the treatment by irrigation of all the sewage of Paris. Since July 10, 1894, a new law has been operative, which authorized the necessary extensions to the existing works and created the necessary funds for their construction. Work was undertaken immediately, and after an interval of five years after the passage of the last law, that is, since July 8, 1899, the discharge of the great intercepting sewers of Paris into the Seine ceased.

Since the last date, supplementary works have been built, and others still remain to be undertaken. It can be said, never-

theless, that at the present time the objects sought have been attained, namely, the entire sewage of Paris, increased by a notable part of the sewage of its suburbs, is regularly applied to purification fields—the only exception being portions of the storm-water flow at times when the sewer overflows are in operation. All the ordinary flows, from 600,000 to 700,000 cubic meters (from 160,000,000 to 185,000,000 U. S. gallons) per 24 hours, are treated systematically on the irrigation fields.

In order to accomplish this result, it was necessary to overcome many technical difficulties in the design of the necessary works; to construct important pumping stations at Clichy (1800 horse-power), at Colombes (6000 horse-power), at Pierrelaye (1200 horse-power); to cross the Seine three times and the Oise once by means of a metal bridge (Argenteuil), a submerged siphon (Herblay), and two tunnels constructed with the aid of compressed air (Clichy and Maurecourt); to create a vast network of reinforced concrete conduits (200 kilometers, or 125 miles) from 0.10 to 1.10 meters (4 to 44 inches) in diameter, for the distribution of the sewage; to establish drains for the return of the purified sewage to the Seine and Oise; to prepare some 800 hectares (1980 acres) of agricultural park lands at Acheres, some 500 hectares (1235 acres) of city land at Mery, and to acquire and put in a state of cultivation the properties at Fonceaux (200 hectares, or 495 acres), at Gresillons (100 hectares, or 247 acres), and at Picquenard (200 hectares, or 495 acres). The cost of these works was more than 45,000,000 francs (about $9,000,000).

Only a small part of the sewage from the collectors is able by gravity to reach one of the purification fields, that at Gennevilliers. The remainder flows to the receiving basin at the pumping station at Clichy, where the larger solid matters are retained and are removed by dredges discharging them into boats, by which they are taken away. The floating matters which are removed by screens are detached from the latter by moving rakes, and are conducted by mechanical conveyors to an apparatus where they are compressed so that they can be finally disposed of by burning. The sewage thus deprived of its coarser matters is lifted by centrifugal pumps, operated by steam or electricity, partly to the plain of Gennevilliers and partly to the pumping station at Colombes. At the latter station it is again raised, by means of piston pumps operated by steam, after a

second sedimentation in a basin designed to retain all suspended matters having a specific gravity equal to that of water, and directed to the other purification fields except the higher portion of the plateau of Mery, which necessitates a third pumping by machines of the same type, located at the pumping station at Pierrelaye.

The annual expense of operation and maintenance reaches a sum of more than 3,400,000 francs (about $700,000).

The irrigated fields of Gennevilliers and Acheres (those comprising the domains of Fonceaux and of Picquenard), as well as those at Carrieres and Triel (those comprising the domain of Gresillons) are ancient alluvial deposits of the river Seine, composed of sand and gravel and having a thickness for filtration purposes of from 2 to 6 meters or more (from 6 to 20 feet). They are extremely porous, and in them the sewage is filtered very easily. Toward the sloping banks of the stream, however, there are modern deposits of muddy sand, which make it necessary at intervals to provide outlet pipes connected to the collecting drains. These serve to insure the proper removal of the filtered sewage and to prevent the ground-water from reaching too high a level. The plateau of Mery (Pierrelaye) presents an entirely different appearance. It is about 55 meters (170 feet) above the level of the Seine, and forms a filter of variable, but always considerable, thickness. This is composed in part of fine and medium sand, and in part of limestone covered with loam and a thin layer of soil. The purified sewage quickly caused the ground-water to rise, making it necessary to provide artificial outlets into the natural ravines leading down to the river Oise.

Methods of Control.—There are two methods by which these irrigation areas are conducted:

In part the city owns the lands (1800 hectares, or 3450 acres), renting them to farmers for an annual sum subject to the requirements of the purification process. That is, the tenants receive stipulated quantities of sewage at all times, night or day, and raise their crops, under permanent supervision and control.

By the second method the remaining 3500 hectares (8650 acres) belong to individuals, who receive the sewage when and as the interests of cultivation call for it, and without having to pay any ground rent.

Under this procedure an important increase in the value

of lands has resulted, especially in those privately held, which have quintupled in value, at least, at Gennevilliers, where they are devoted to the cultivation of vegetables for the Paris market. The other areas have also gained in value each year, although the greater distance and lack of labor prevents farming on any but a large scale, the raising of cereals, potatoes, etc.

The operation of the irrigation system is controlled by commissions under the higher board of administration. They are compelled by law to present half-yearly reports and to see that the legal amount of sewage is distributed to the fields under cultivation without the formation of stagnant pools. These reports have never failed to show that directions have been carried out properly, and to attest to the satisfactory operation of the system. Proof of this one finds, among other ways, in the popular satisfaction which has succeeded the violent opposition first encountered; in the general eagerness of the agricultural population to take advantage of the fertilizing properties of the sewage to make their farms more remunerative; in the increase of population in the localities adjoining the purification fields (that at Gennevilliers has tripled since the commencement of irrigation); and in the maintenance locally of normal sanitary conditions.

Purification.—As to the degree of purification, results, without exception, have been obtained which are certainly unequalled elsewhere, either by sewage irrigation or by any other process. The filtered sewage leaving the underdrains and entering the Seine or the Oise is invariably limpid and of admirable quality. Chemical and biological analyses show it to contain a proportion of organic matter and bacteria which (were it not for the richness in chlorine and nitrates, an unmistakable index to its origin) would permit it to be classed with potable waters of good quality. Table 82 gives a sample of the results in parts per million regularly obtained at the laboratory of Mountsouris with regard to the composition of the filtered sewage; and, for purposes of comparison, also some analyses of the raw sewage itself and of the ground-waters used as the domestic supply of the city of Paris.

TABLE 82.—AVERAGE ANALYTICAL RESULTS FOR THE YEAR 1901

Constituents	Raw sewage (Clichy)	Filtered sewage				Ground-waters			
		Gresillons outlet (Gennevilliers)	Herblay outlet (Achères)	Liesse outlet (Méry)	St. Blaise outlet (Carrières)	Dhuis	Vanne	Avre	Loing
Mineral matter (lime)	152	307	259	182	263	107	117	84	113
Organic matter	33.4	1.1	1.7	0.9	1.1	0.6	0.4	0.7	0.3
Chlorine	52	83	72	27	68	7	5	11	7
Nitrogen as Nitrate	0.8	28.2	19.1	19.7	21	2.1	2.2	2.4	3.7
Nitrogen as Ammonia	15.4	0	0.2	0	0	0	0	0	0
Nitrogen as Organic	6.7	0	0	0	0	0	0	0	0
Bacteria, per cubic centimeter	148,322,000	585	1000	125	250	1765	760	785	925

BERLIN SEWAGE FARMS

The first of these farms was put in service in 1876 and since that time they have gradually increased in area until in March, 1910, the total area was 43,009 acres. The main features of this project are described in detail in a paper by Mr. H. Alfred Roechling before the Institution of Civil Engineers of Great Britain in April, 1892. The more recent features are also detailed in a paper by Mr. Roechling read before the Royal Sanitary Institute in November, 1911. The latter paper of Mr. Roechling is based upon the Annual Report of the Berlin Farms for the Year ending March 31, 1910, and is printed in *The Surveyor* of Nov. 17, 1911. It is the source of most of the following data.

The average volume of sewage treated by the Berlin farms amounted in 1910 to about 77 million U. S. gallons daily, equal to about 35 gallons per capita daily. This sewage is pumped to a light sandy soil through which it percolates quite readily. There are 12 pumping stations which deliver the sewage to eight farms, three of which are to the south and five to the north of Berlin. The northern farms range from 4 to 17 miles from the center of the city; the southern farms from 8 to 17 miles. The centers of the northern and southern farms from the center of the city are 9.5 and 12.5 miles, respectively.

The sewage is pumped through cast-iron mains to stand pipes 25 feet high located at the highest points on the farms. It then passes through earth settling basins from which it is distributed to the various plots by means of earth carriers. From the report of March, 1910, it is noted that the sewage farms have been developed to the following extent:

	Farmed by city authorities	Let to small farmers (market gardeners)	Permanently or temporarily unproductive	Total
Acreage prepared and under sewage treatment	16,657	3,956	395	21,008
Acreage unprepared and farmed in ordinary way	10,647	2,486	8,868	22,001
	27,304	6,442	9,263	43,009

The large unproductive area seems to be explained by its being in the process of gradual preparation for sewage treatment.

Mr. Roechling states that at the end of 1910 the total prepared area of all farms had increased to 22,851 acres as follows:

A. Used for broad irrigation, grass plots		7,994 acres
B. Used for filtration beds,	12,250 acres	
Used for settling basins,	502 acres	
		12,752 acres
C. Subsidiary works		126 acres
D. Occupation roads		1,979 acres
Total		22,851 acres

The acreage underdrained was on Mar. 31, 1910, as follows:

Prepared land	21,019 acres	
Unprepared land	363 acres	
Total	21,382 acres,	with 9,257 outlets.

The total capital cost of purchasing the farms, of laying them out, of erecting the necessary buildings, etc., was on Mar. 31, 1910, approximately as follows:

Purchase	$ 9,861,878
Laying out, including sewage distribution, roads, etc	4,455,604
Drainage	1,203,030
New buildings and sundries	1,949,488
Total on Mar. 31, 1910	$17,470,000

The cost per acre of total area and of land specially prepared is given as follows:

	Total area	Land specially prepared
Purchase of land	$229.38	$431.52
Laying out, including distribution of sewage, roads, etc	103.50	195.12
Draining land	27.90	52.68
New buildings and sundry expenses	45.42	85.26
Total capital expense per acre	$406.20	$764.58

A summary of the receipts and expenditures of the sewage farms, excluding sewers and pumping stations, for the year ending Mar. 31, 1910, is as follows:

Receipts	$1,240,772.58
Net increase of valuation in live and dead stock	122,593.50
	1,363,366.08
Deduct payments for maintenance	1,300,385.34
Profit on year's work	62,980.74
Payment of interest and payment of loans	741,718.62
Deduct profit on year's work	62,980.74
Deficit, to be made good from taxes	$678,737.88

The average rate of filtration in 1910 through the prepared land under treatment (about 21,000 acres) was about 3700 United States gallons per acre daily. Mr. Roechling states that the proportion of land receiving sewage at one time has at different intervals during the existence of the farms ranged from about 3 to 6 per cent. This means that at a single dosing volumes of sewage have been applied at rates of 50,000 gallons per acre daily and more. Fortunately the character of the soil is such that this is feasible. It is significant to note that the reports record the area of filtration beds as about 50 per cent. in excess of the area used for broad irrigation. The annual rainfall averages about 23 inches.

As to farming operations, the more important crops are rye, wheat, barley, oats, Indian corn, potatoes, beets and carrots.

The effluent is stated to be of good quality. It is conducted through ditches to fish ponds, the area of which in 1910 was 40 acres. The income from the fish ponds amounted to about $80 per acre per year, or more than is customarily obtained from the sale of crops from land. Notwithstanding the fertilizing elements which the sewage conveys to the land, the returns indicate moderate or average rather than unusually large yields of crops.

PRESENT STATUS OF BROAD IRRIGATION

In America this process has almost no standing as an independent method of purifying sewage in the humid regions of the eastern and middle sections. Its use is an incidental feature at a few intermittent sand filtration plants.

In the arid regions there are almost no instances of broad irrigation or sewage farming that are carried out in a sanitary way giving a permanently satisfactory means of sewage disposal.

In Europe much more success has attended various sewage farms, but they have not been money-making institutions. As a means of sewage disposal, however, they are far in advance of anything of this type in America. This is due partly perhaps to the favorable soil conditions, as at Paris and Berlin, but principally to careful and efficient management.

One of the few instances where the revenue has exceeded the interest on the investment was during 1902–03 at Melbourne, Australia, as stated by Mr. W. Thwaites in the *Transactions of the American Society of Civil Engineers*, Vol. LIV, Part E, pages 214–30. Even there the financial showing for that year was exceptional by reason of a drouth and the fact that large numbers of sheep were bought cheaply, fed on the farms and sold at a high price.

In England sewage farming or broad irrigation is still practised quite extensively. Under many conditions lack of porosity of the soil is quite a handicap. On the whole, broad irrigation seems to be on the wane and filters of artificial construction are superseding it. This is well illustrated by Mr. Watson's experience at Birmingham.

Prof. Calmette made a careful study of conditions on the

Paris farms and concluded that broad irrigation would probably become more and more restricted and ultimately abandoned. Dr. Dunbar gives a similar conclusion with respect to the Berlin farms in the closing pages of his book on "Sewage Treatment" published in 1908. He states that many of us will live to see the day when Berlin will sell its farms for building purposes and construct biological works in their place.

The conclusions just stated are supported by the fact that some of the suburbs of Paris and Berlin are building sprinkling filters rather than adopting broad irrigation. In the *Engineering Record* of Aug. 19, 1911, a description is given of the sprinkling filters built for the southern suburbs of Paris at Mount Mesly. In *Engineering News* of Mar. 19, 1908, will be found a description of a sprinkling filter plant built at Wilmersdorf, to serve certain suburbs of Berlin.

RÉSUMÉ

In America broad irrigation or sewage farming is not practised to-day even in the arid regions so as to give satisfactory results for the sanitary disposal of sewage. There may be scattering exceptions to this statement, but an examination of the present facts does not bear out earlier reports that broad irrigation is really used regularly and carefully in numerous places.

Objections to the method have increased rather than decreased in recent years. These relate to objectionable odors, prejudices against the use of sewage in growing vegetables and to the transmission of disease germs by flies and other insects.

Experience shows that only nominal aid financially has been received from the use of sewage in broad irrigation.

The present outlook is that broad irrigation or sewage farming is decidedly on the wane with little prospects of adoption even in the arid districts except perhaps for an occasional project where local conditions are unusually favorable.

CHAPTER XIX

INTERMITTENT SAND FILTRATION

This method consists in applying comparatively small volumes of sewage to areas of porous sand, allowing the sewage to drain from the pores of the material, which fill with air, and in repeating the dose of sewage some hours or days later. The process has been described as allowing sewage to remain in the pores of the sand filter for a sufficient time, in the presence of air and the necessary bacteria, including nitrifying organisms, which become established on the sand grains. This treatment results in a large portion of the putrescible organic matter being converted into stable mineral matter (nitrates).

Continuous filtration of sewage with the pores of the sand filled with liquid, like the continuous filtration of water on sand beds, is impracticable because it prevents the entrance of sufficient air to bring about oxidation. Hence putrefaction within the filter would result quite soon, nitrification would disappear and the process would consist simply of removing suspended matters by straining.

NOMENCLATURE

The treatment of sewage by this process is generally spoken of as "intermittent sand filtration." In its early days in England the process was sometimes spoken of as "intermittent downward filtration." Some speak of it as "sand filtration" or "biological filtration." There has been practically no confusion as to nomenclature and the expression "intermittent sand filtration" is so generally used that there is no likelihood of misunderstanding.

HISTORICAL DEVELOPMENT

In the laboratory this process had its origin in 1865 to 1870. While no conception was held at that day as to the intricacies of the biological functions which are essential to success, some of the principles were grasped in a way that seems rather sur-

prising when it is considered that this knowledge antedated the dawn of bacteriology as a science.

That sewage could be purified through digestion and mineralization by small animal and vegetable life was known in 1865 to Dr. Alexander Mueller, a well-known chemist of Berlin. At that period the most important work, however, on intermittent filtration was carried on by the late Sir Edward Frankland in connection with his investigations on the Rivers Pollution Commission of Great Britain. In laboratory experiments Dr. Frankland found that sewage could be filtered so as to produce a good effluent when applied in a downward direction through coarse gravel at a rate of about 80,000 gallons per acre daily. He realized the necessity of intermittent application to prevent overloading and noted the production of a poor effluent with too large a quantity of sewage; also that in a good effluent much of the objectionable organic matter was converted into harmless mineral matter. He developed the chemical aspects of the process as distinguished from the mechanical or physical, but he did not grasp the biological significance of the method.

First Application.—The first application of this process on a practical scale was by the late Mr. J. Bailey-Denton, who in 1871 constructed a plant of some 20 acres in area at Merthyr-Tydvil, Wales. This classical plant was operated originally at an average rate of about 60,000 gallons per acre daily with sewage applied for about 6 hours out of the 24. This plant seemed to work well, and it was considered an important demonstration of this process as recommended by Frankland. The surface of the filters was cropped and gradually their area was extended so that in later years the plant has lost its individuality as an intermittent sand filter plant and has become practically an irrigated area or sewage farm.

This process made comparatively little headway in Europe against the prevailing practice of broad irrigation and chemical precipitation. This is not doubt explained to a considerable extent by the comparative absence of suitable areas of sufficiently porous material near at hand. Scientifically the process, however, continued to receive attention. In 1877 it was demonstrated by Schloesing and Müntz in France that the purification of sewage in this manner is due to living organisms and that nitrification did not occur in soils which have been sterilized by heat or by chemicals. Dr. Mueller of Berlin continued his active

interest in the matter and in 1878 took out a patent for a "process for the disinfection, purification and utilization of sewage by the scientific cultivation of yeast-like organisms." Further light on the process was obtained in 1882 by Dr. Warington, of England, who contributed considerable reliable information as to the nitrifying processes as related to this method of sewage treatment.

Bacteriology was now beginning to receive considerable attention along lines similar to the present procedures, and effort was directed by several workers to the isolation of those bacteria which bring about nitrification. This expression refers to the process by which organic matter is converted or oxidized into harmless mineral matter, nitrates. Progress was slow because it was found that the nitrifying bacteria do not thrive on the ordinary culture media of the laboratory nor, in fact, on any culture media which are rich in organic matter. With the aid of special inorganic media Dr. Frankland and also Winogradsky in 1890 succeeded in isolating this group of organisms which carried on the complete cycle of nitrification. Profs. Richards and Jordan in Massachusetts and Dr. Warington in England confirmed these results shortly thereafter. Beginning in 1887 the Massachusetts State Board of Health established at Lawrence, Massachusetts, the well-known experiment station, where, on a working scale under conditions encountered in practice, the laws pertaining to the intermittent sand filtration of sewage were developed from a biological, chemical and engineering standpoint. As already stated the annual reports for more than 20 years of the investigations at Lawrence constitute the most important addition from a single source to the literature of this and allied subjects. Geologically, Massachusetts is fortunately situated with respect to having areas of porous sand near many of its centers of population. Under these circumstances the scientific investigations at Lawrence have had coupled with them various observations as to the actual working methods in plants established by numerous towns and cities in that state. In this as in other chapters use will be made freely of the vast fund of information which has been collected by the Massachusetts State Board of Health under the guidance of Mr. Hiram F. Mills, who for more than 25 years has been Chairman of the Committee of the Board on Water Supply and Sewerage.

EXTENT OF USE

In 1904 there were 41 intermittent sand filters in operation in the United States serving a population of about 250,000 people. The majority of these plants were located in New England and about half of them in Massachusetts, according to the data secured by the author for a paper prepared for the International Engineering Congress in that year. These tabulated data appear on pages 155–58 of the *Transactions of the American Society of Civil Engineers*, Vol. LIV, Part E.

Since 1904 a number of intermittent sand filter plants in New England have been enlarged, and a few new ones have been built. Outside of New England sand filters have been recently installed at quite a number of places in conjunction with coarse-grained filters. These filters in many cases are of artificial construction and illustrate the striking disadvantage in point of cost and feasibility of plain sand filters in many sections of the country where porous sandy soil in ample area is not available for sewage purification. In New Jersey there are about 15 intermittent sand filters now in operation, but nearly all of the newer ones receive sewage from contact filters. Among this number may be mentioned those at Bordentown, Chatham, Merchantsville, Morristown, Roebling, Washington, etc. In Ohio there are about 9 municipal and 15 institutional sand filter plants, all of which are comparatively small and most of which are used in conjunction with some other form of sewage treatment.

EFFICIENCY

Under this heading we shall speak particularly of intermittent sand filters as used without preliminary treatment other than coarse screens or very small tanks, practically grit chambers.

A higher degree of purification, generally speaking, can be obtained by this process than by any of the others in use, excepting the allied method of broad irrigation. When the filters are operated under favorable conditions the effluent is practically free from turbidity and odor; and it is stable; that is, it will not decompose upon standing. Filtered sewage usually contains only about 1 per cent. or so of the number of bacteria present in raw sewage, the degree of removal depending much on the kind of sand.

TABLE 83.—RATE OF FILTRATION AND AVERAGE RESULTS OF ANALYSES OF EFFLUENTS OF MASSACHUSETTS SAND FILTERS

(Parts per million)

City or town	Quantity of sewage treated per acre per day (gallons)	Residue on evaporation	Ammonia		Chlorine	Nitrogen as		Oxygen consumed	Hardness	Iron
			Free	Albuminoid		Nitrates	Nitrites			
Concord	94,500	175.6	0.017	.104	25.9	8.467	.000	1.1	51	0.041
Brockton	40,900	531.7	2.250	.166	111.3	30.750	.103	3.3	36	0.601
Spencer	40,300	179.5	1.484	.186	31.6	3.691	.248	3.3	61	3.542
Framingham	32,800	285.1	2.169	.186	51.7	9.854	.151	2.6	64	3.610
Stockbridge	37,500	199.5	0.990	.207	18.1	1.630	.025	3.0	98	1.288
Natick	51,000	206.2	6.150	.319	40.4	2.217	.195	4.4	58	2.290
Pittsfield	67,200	333.8	2.626	.365	22.9	6.674	.198	3.8	131	0.266
Southbridge	48,300	109.6	3.865	.369	17.4	2.036	.126	3.6	31	1.039
Marlborough	99,800	270.5	12.365	.622	59.7	3.521	.272	7.3	63	3.016
Andover	34,200	260.7	11.040	.677	53.7	8.325	.161	7.4	48	5.097
Gardner (Templeton system)	134,200	256.9	7.761	.698	30.4	15.180	.196	5.8	58	0.397
Clinton	33,400	416.6	10.173	.774	55.5	4.399	.199	11.2	64	11.992
Leicester	55,600	236.7	7.065	.813	39.4	9.117	.367	9.6	47	0.981
Gardner (Gardner system)	120,800	234.8	17.990	.841	30.2	0.442	.047	10.7	61	13.567
Westborough	70,500	155.4	6.410	.849	22.2	3.571	.528	7.3	38	0.469
Hopedale	65,200	233.9	10.440	.888	24.9	15.856	.256	7.2	53	0.214

Practical accomplishments by the intermittent sand filters of Massachusetts are well reviewed by the Massachusetts State Board of Health in their Annual Report for 1903, pages 309–455. Tables 83–4 taken from page 448 of this report, show concisely the rate of filtration and the purification effected at sixteen of the principal sewage filters in Massachusetts.

TABLE 84.—PURIFICATION EFFECTED BY MASSACHUSETTS INTERMITTENT SAND FILTERS

(Percentages of removal)

Place	Free ammonia	Albuminoid ammonia	Oxygen consumed
Brockton	95.8	98.9	98.5
Framingham	93.2	97.6	94.4
Spencer	91.8	96.6	92.9
Pittsfield	82.0	96.3	95.2
Concord	99.8	93.9	91.9
Clinton	74.8	91.9	90.1
Southbridge	80.2	91.4	91.0
Gardner (Templeton system)	76.6	91.3	90.4
Natick	58.4	90.0	86.5
Andover	77.1	90.0	84.9
Stockbridge	91.6	89.6	79.9
Marlborough	60.7	88.5	83.6
Gardner (Gardner system)	26.6	86.0	78.3
Westborough	61.8	84.3	79.4
Leicester	73.5	83.8	81.1
Hopedale	53.0	73.9	75.8

CAPACITY

In a paper prepared in 1905 by the author, from the data then available from the Massachusetts State Board of Health reports, it was found that the principal experimental filters at Lawrence, then in service for 17 years, showed rates of filtration as given in the next table. These Lawrence data refer to the outside filters and not the small indoor tanks. In this table the "load" carried by the several Lawrence intermittent sand filters is expressed in terms of the number of persons contributing sewage per acre of filtering surface. This computation was made by the author on the basis of the amount of applied nitrogen in

the influent of the filters as given by Mr. Clark in the 1904 Report of the Massachusetts State Board of Health, pages 212–15, and on the assumption that each person at Lawrence contributes to the sewage 13 grams of nitrogen daily on an average.

TABLE 85.—COMPUTATIONS OF LAWRENCE SAND FILTER LOADS, 1904

Number of filter	Kind of material	Effective size in millimeters	Years in service	Average gallons per acre, daily	Average number of persons per acre
1	Coarse sand	0.48	17	61,110	730
2	Fine sand	0.08	17	31,700	380
4	Very fine sand	0.04	17	20,200	260
6	Sand and gravel	0.35	17	49,200	630
9	Medium sand	0.17	14	60,300	785

Such rates as indicated by the above are not wholly in accord with some of the data of sand filter plants in actual practice in Massachusetts. Where the rates in practice are recorded as much higher it is believed that they represent only a short period of loading and that filter extensions must soon follow. Other cases in Massachusetts are to be found where the rates in practice are lower than necessary. In this connection it is of interest to compare the data from the 1903 Report of the Massachusetts State Board of Health.

TABLE 86.—MASSACHUSETTS SAND FILTER LOADS, 1908

Place	Population[1]	Place	Population[1]
Andover	950	Natick	360
Brockton	1,160	Pittsfield	605
Clinton	425	Southbridge	305
Concord	365	Spencer	320
Framingham	375	Stockbridge	220
Gardner (Old)	1,310	Westboro	750
Gardner (New)	2,000	Worcester	1,390
Marlboro	840		

[1] Population connected with sewers for each acre of filter.

In studying the above table it is necessary to bear in mind that some of the filters, such as at Framingham, are operated at rates lower than could be regularly maintained if need be. Some of the newer filters also show similar loadings on account of the plants having been built to provide for a greater population than was connected with the filters at the outset. On the other hand, intermittent sand filters for short periods can operate quite satisfactorily with loads materially in excess of those which would be economically advantageous through a term of years. The figures given for Brockton are probably high, partly on account of the filter beds having been pushed with a heavy load at a time just prior to extension. The effect of this loading was shown in 1905, when it is understood that clogging was manifest to an extent which resulted in about 6 inches in depth of the surface material being removed from about three-quarters of the entire filter area. The data above given as regards the new filters at Gardner and also those at Worcester, particularly the former, are to be considered in relation to the preliminary treatment of the sewage for the purpose of clarification. These data, furthermore, as a group are to be considered as applicable to the flow of separate sewers as distinguished from those built on the combined plan and receiving street wash. At Worcester trade wastes were considerable of a factor, and this is true to some extent at a number of other places.

Lawrence Evidence.—As showing the relation between the experimental filters at Lawrence and those operated on a practical scale in Massachusetts, the best testimony is that of Messrs. Clark and Gage in their review of 21 years' experiments upon sewage purification in the Report of the Massachusetts State Board of Health for 1908, pages 251–538. Their conclusions on intermittent sand filtration of sewage are given on pages 349–50, as follows:

The efficiency and permanence of sand filters have been demonstrated so well in Massachusetts by the past 20 years' work of these experimental filters and the municipal filters in operation at many cities and towns that little need be said as a summary other than the facts already given. The filters at the station have been operated more carefully and the essential facts of their operation and results more fully recorded, however, than could have been possibly the case at any of the municipal filters; the results obtained from them, therefore, are of especial value. It is of interest to know that the principal sand filters,

started late in 1887 or early in 1888, from the coarsest to the finest, have been kept in successful operation without undue clogging, and that removal of clogged surface sand has not been necessary during the past 16 years. It is also important to note that the effluents of these filters during 1908 were considerably better than the average maintained during the entire period of 21 years, and approximated in purity the effluents obtained when the filters were first put into operation.

The essential facts in regard to the working of sand filters have been given in previous pages. Some of them may be summarized, however, as follows: (1) better effluents can be obtained by sand filtration of sewage than by any other method of sewage treatment; (2) rates of filtration must be low compared with the rates that can be maintained with contact and trickling filters, as described later in this report; (3) with sewage as strong as that at Lawrence—probably stronger than average American sewage—it is inadvisable to undertake to operate the best sand filter at a rate exceeding 75,000 gallons per acre daily, and with fine sands the rate must be much less; that is, these rates cannot be exceeded if absolute permanence of the filter area is desired; (4) sand filters properly cared for and not overworked are practically permanent; (5) sand removal is at times necessary, especially if systematic care is not given to the filters, and if the rate of application and the quality or strength of the sewage overloads the filter, in other words, if the rate maintained causes the application of a greater body of organic matter than the biological life of the filter can adequately care for; (6) a certain portion of the suspended organic matter in sewage retained by sand filters is stable, and resists for long periods changes due to chemical and biological forces—it is practically as stable as the organic matter of soil; (7) the rate of filtration should be proportioned to the strength of the sewage, as shown by the organic matter contained in a given volume of water and especially the organic matter in suspension; (8) when the rate of application of sewage goes beyond a certain normal point, sand removal becomes necessary. Furthermore, the amount of sand that must be removed increases more rapidly than the rate, as shown by the figures on page 334; (9) preliminary treatment of sewage as previously described allows sand filters to be operated more or less satisfactorily at rates much greater than is possible with untreated sewage, as instanced by the results obtained with filters Nos. 13A, 19A, 14A, 100, 12A, 53, 54, 55, 56, 57, 58, 224, 249, 250, etc., on pages 338–344, inclusive.

Ohio Evidence.—In the Special Report of the Ohio State Board of Health, published in 1908, containing the results of the examinations of the sewage disposal plants in that State, Mr. Kimberly gives the following summary on page 711:

The rates of operation of the sand filters in Ohio vary widely, depending upon the character of the filtering material and the extent to which the sewage is clarified before final treatment. In the next table (omitted) are shown the average rates of filtration, the population load per acre, the extent of the preparatory treatment and the general efficiency of all of the sand filter plants examined. Rates of treatment range from 17, 500 to 1,200,000 gallons per acre daily, and it is evident that preparatory treatment, broadly speaking, makes possible about double the rate where crude sewage is applied to the filters.

The population loads which are perhaps the best basis show a range from 250 to 2650 for no preliminary treatment and from 600 to 14,500 when a preparatory process is employed. Certain anomalies appear in the table and are perhaps explained by uncertainties in the data as to the population served. However, available information indicates that to insure good results in actual practice the application of crude sewage to sand filters constructed of a good quality of bank or lake sand, the population load per acre should not be greater than from 500 to 600; when preceded by sedimentation in settling or septic tanks the load may be increased to from 1000 to 1200.

Summary.—The Local Government Board of England prescribed among other rules about 1890 that at least one acre of intermittent sand filters should be provided for each 1000 population connected with the sewers. With the severe winter weather in the northern parts of America and the greater volume of liquid to be dealt with per capita, it is the judgment of the author that 1.5 acres of intermittent sand filters per 1000 population is as small an area of actual filtering surface as should be provided for the treatment of sewage that is not well clarified by some preliminary process. Indeed, if the filtering material should be very fine, the area should be much greater than 1.5 acres. Unsettled sewage requires a greater area than settled sewage unless the operating expenses are allowed to become abnormally high. Where sewage is subjected to a preliminary treatment which affords substantial clarification these rules do not apply, as it is quite feasible to operate the filters at higher rates with consequent smaller areas of filtering surface.

RELATION TO PRELIMINARY TREATMENT

The efficiency of intermittent sand filters is so high that they do not require under favorable conditions the construction and operation of any subsequent treatment works. They in them-

selves constitute a satisfactory final treatment for the effluent of coarse-grained filters under some circumstances. This subject will be treated subsequently.

Concerning preliminary treatment, to provide partial clarification and purification of sewage before it is applied to intermittent sand filters, this is an important question upon which the evidence is by no means on a satisfactory basis at present. A few years ago it was considered by many as quite unnecessary to give the sewage any preliminary treatment at plants where the filters could be built economically, such as at some places in New England. As the needs of sewage purification extended to other sections of the country where suitable porous areas of sand were not readily at hand, increased attention has been given to sludge removal and to means of keeping the surface of the filters in as porous a condition as possible so as to increase the volume of sewage that can be satisfactorily treated, on a unit of filtering area.

The rate of filtration bears in a general way an inverse relation to the strength of the sewage. In other words, as was shown at Lawrence (1901 Report, page 306), if one sewage contains one-third as much organic matter as another, it can be filtered, under equal conditions, at about three times as high a rate, and there will be substantially the same quality of effluent in each case. Especially valuable in considering this proposition are data obtained from filtering sewage from the same source, but from which organic and suspended matters have been removed, prior to filtration, in different amounts and by different methods. Such data are contained in the following table, where are given the average results of investigations made at Lawrence during many years from a series of filters containing approximately the same size of sand, and to which was applied, in one instance, the raw station sewage and, in others, the same sewage after it had been partially treated by chemical precipitation, plain sedimentation, septic treatment, straining through coke and in other ways. With the quality of the effluent approximately the same, it is seen that the rates of filtration are much higher in those filters receiving a partially purified sewage.

Baltimore Project.—In connection with the project of purifying the sewage (estimated at 100 gallons per capita) for the city of Baltimore, Messrs. Hering, Stearns and Gray in 1906 determined that settled sewage from which about two-thirds of

TABLE 87.—AVERAGE DATA SHOWING RATES OF FILTRATION AND COMPOSITION OF INFLUENTS AND EFFLUENTS OF 5-FOOT FILTERS AT LAWRENCE CONTAINING MEDIUM FINE SAND, AND TO WHICH WAS APPLIED THE STATION SEWAGE AFTER RECEIVING VARIOUS KINDS OF PREPARATORY TREATMENT

Filter Number	Effective size of material, in millimeters	Preparatory treatment received by influent	Years covered by averages	Average number of gallons applied per acre daily for 7 days in the week	Influent						Effluent					
					Parts per million						Parts per million					
					Oxygen consumed	Nitrogen as ammonia		Free	Chlorine	Bacteria, per cubic centimeter	Oxygen consumed	Nitrogen as				Bacteria per cubic centimeter
						Albuminoid						Ammonia		Nitrates		
						Total	Susp.					Albuminoid	Free			
9*a*	0.17	None	1891–1902	58,688	40.0	7.20	3.09	35.0	87.5	2,299,000	4.8	0.462	7.35	23.60		12,400
12*a*	0.19	Filtered through coarse gravel, aerated	1892–1897	503,030	10.1	1.43	.....	7.1	92.0	273,000	2.4	0.214	2.57	20.46		1,500
13*a*	0.19	Sedimentation	1893–1897	177,049	30.6	4.27	1.61	31.8	98.4	2,100,000	2.9	0.324	4.43	24.66		4,300
14*a*	0.19	Strained through coke	1894–1899	236,587	22.0	3.10	0.98	28.8	93.2	1,194,000	2.9	0.248	2.04	25.40		1,300
19	0.17	Chemical precipitation	1893–1897	188,065	20.9	2.80	0.81	30.8	93.8	924,000	2.6	0.266	3.59	27.14		2,400
100	0.26	Septic treatment	1898–1902	208,024	26.3	3.19	1.21	36.2	97.2	743,000	7.5	0.731	7.79	27.90		62,900
116	0.17	Septic treatment	1898–1902	184,235	30.0	3.51	1.03	38.1	86.1	881,800	3.6	0.287	3.24	31.40		1,600
118	0.23	Septic treatment, aerated	1899–1902	212,253	32.4	3.56	1.13	37.4	81.1	1,067,500	6.8	0.562	5.19	26.30		12,000

the total suspended matter had been removed could be applied at an average rate of 150,000 gallons per acre daily to intermittent sand beds containing 3 feet in depth of clean washed sand having an effective size from 0.25 to 0.35 millimeter. It was recognized, however, that the fine suspended matter contained in the influent would gradually clog the surface of the sand so that ultimately the clogging could not be removed by harrowing the surface. Sooner or later solid matters would work gradually into the sand, so that it would be necessary occasionally to remove a layer of surface sand. It was estimated that the depth of sand thus removed annually would be from 2 to 2.5 inches, and would amount to from 5 to 6 cubic yards per million gallons of sewage filtered. The average cost of caring for these beds was estimated at $325 per acre annually. Intermittent sand filters at Baltimore, estimated to cost $6350 per acre, exclusive of land, were regarded as too expensive on the loading above given, because satisfactory results could be obtained more cheaply with the aid of sprinkling filters which were recommended and built.

Clogging Features.—This question of clogging incidental to high rates even with clarified sewage involves an expense for maintenance which goes a long way toward offsetting economies in construction resulting from high rates and small areas. It is difficult to equate in general the advantages and disadvantages of the clarification of sewage for treatment on this style of filters, for the reason that important local conditions vary widely.

There are two aspects to this question of preliminary treatment: One is that of removing clogging, with its attendant expense, so as to allow sufficient air to enter the pores of the filter for purposes of oxidation and nitrification. The other relates, for the given rate, to keeping the total load of organic matter of an unstable character in the influent within limits which do not overtax the oxidizing or nitrifying capacity of the filter. Plain sedimentation will remove about two-thirds of the total suspended matter in crude sewage, but only about one-third of the total organic matter. The question is still unsettled as to whether intermittent sand filters in consequence of preliminary clarification of the influent may have their loads increased corresponding with the removal of suspended matter in settled sewage or corresponding with the removal of total organic matter. In the former case the loadings could be

tripled and in the latter case they could be increased 50 per cent., keeping the respective constituents of the influent constant. In a general way it appears that the latter viewpoint is the more rational, provided in all cases reasonable attention is given to the filters to free them from clogging. In this connection reference is made to the discussions of Messrs. Clark and Gage in the 1908 Report of the Massachusetts State Board of Health, pages 325–35. Messrs. Eddy and Fales found complications from clogging at Worcester when sand filters received clarified sewage, especially from chemical precipitation tanks as described in their Boston paper of 1906. Mr. Johnson found similar difficulties at the Columbus sewage testing station. On the other hand, Profs. Winslow and Phelps speak very favorably of high rates for sand filters receiving the effluent of the Boston biolytic tank, as stated in the *Journal of Infectious Diseases*, April, 1911, page 272.

INTERMITTENCY AND RELATION TO OXYGEN

Intermittency is a *sine qua non* of the successful filtration of sewage by intermittent sand filters. As has been known for many years, when sewage filters are operated continuously, the oxidizing processes come to an end and then anaerobic processes set in, with the result that there is obtained an effluent that in some ways is less satisfactory than the influent. To secure good results, not only must sewage sand filters be operated intermittently, but the schedule of operation must be such that sufficient air is allowed to enter the pores of the sand so as to maintain bacterial functions upon an oxidizing and not upon a reducing basis. These processes become established through bacteria which locate themselves within the filter and there grow under all ordinary circumstances. For these processes to work advantageously it is desirable to provide some oxygen within the pores of the filters at all times and at all places. Whatever tends even temporarily to cut off the supply of oxygen is a handicap, both from the theoretical and practical standpoint, as to the accomplishments of the filter. A surplus of oxygen, on the other hand, is not helpful to oxidation processes as compared with a well-defined small amount always present at all places. In explanation of this process the author has compared the relation of the necessary bacteria in the filter to oxygen with a person who desired to satisfy his appetite with beefsteak.

It makes no difference whether a person has constantly before him one forkful or one pound or one ton of beefsteak, as in either case there will be a sufficiency until his capacity to eat the steak is exhausted. In the same way, if the oxidizing and nitrifying bacteria have at all times and places some oxygen with which to carry on their life processes, then they will do as satisfactory work as when there is a great surplus present. This matter was one of the most important discoveries made in the early work at Lawrence, and is described at length in the Special Report of the Massachusetts State Board of Health, 1890, Part I, page 730. A condensed statement of these tests and conclusions is given by Messrs. Clark and Gage in the 1908 report of the same Board, page 357, as follows:

All of the experiments thus far described have been made with filters of such open material that there is an abundance of oxygen in every part. With continuous filtration there is no nitrification, and there is reason to believe that this is due to the lack of oxygen. Still, the movement of liquid through the sand is different in continuous and intermittent filtration, and it was desirable to make experiments in which the conditions of descent of sewage should be exactly like those of intermittent filtration, but from which all oxygen should be excluded. It was also desired to find the minimum amount of oxygen which would support nitrification. For these experiments Tank No. 14 was used.

The bottom of the tank was trapped, and a cover put on the top, attached to the tank by a mercury seal, which made it air tight. Sewage was put in through a large funnel with a stop-cock, so that no air was admitted, and a perforated plate distributed it over the surface. The effluent was free to pass the trap at the bottom, but no air could get back into the tank.

In a week nitrification had stopped and the effluent was little better than sewage.

This experiment was repeated a number of times with the same result, nitrification being established between the successive trials by forced aeration of the filter. The aspirator was then so arranged that that air was drawn from the bottom of the filter and returned to the surface, a small amount of fresh air being admitted from time to time in order that the oxygen should not be entirely exhausted. In these experiments it was found that nitrification was as complete when the oxygen content of the air in the filter was as low as one to three per cent. as when a larger quantity was present, provided a constant circulation of air was maintained throughout the material. (Special report for 1890, pages 730, 731.)

CHARACTER OF FILTERING MATERIAL

The best information available on this subject is that obtained from the experimental filters at Lawrence, Mass. This question is associated with many allied topics on the effective size of sand, the uniformity in size of sand, influence of capillarity, etc. The essence of these propositions was well stated by Mr. Allen Hazen in the Annual Report of the Massachusetts State Board of Health for the Year 1891, pages 428–41. An outline of the Lawrence viewpoint is as follows:

> The purification of sewage by intermittent filtration depends upon oxygen and time; all other conditions are secondary. Temperature has only a minor influence; the organisms necessary for purification are sure to establish themselves in a filter before it has been long in use. Imperfect purification for any considerable period can invariably be traced either to a lack of oxygen in the pores of the filter or to the sewage passing so quickly through that there is not sufficient time for the oxidation processes to take place. Any treatment which keeps all particles of sewage distributed over the surface of sand particles, in contact with an excess of air for a sufficient time, is sure to give a well-oxidized effluent, and the power of any material to purify sewage depends almost entirely upon its ability to hold the sewage in contact with air. It must hold both sewage and air in sufficient amounts. Both of these qualities depend upon the physical characteristics of the material. The ability of a sand to purify sewage, and also the treatment required for the best results, bear a very close relation to its mechanical composition. It is our present purpose to more definitely formulate the results obtained with a view to predict the action of any material from its mechanical composition.

Mechanical Analysis.—Of much practical assistance to the sanitary engineer has been the method of mechanical analysis first developed at Lawrence by Mr. Hazen for showing the more important characteristics of filtering material for sewage treatment. This is so well described in various books and reports that we will not dwell upon the subject in great detail. Briefly, the sand is separated by a series of calibrated sieves into particles having a size that is approximately known. The diameter of the particles passing through the different screens or sieves is assumed to be the diameter of a sphere of equal volume. By actual test there is determined the size of particles which are just barely able to pass through a sieve of known mesh. The percentage by weight of the sand retained on each of a series of

sieves is then plotted as indicated in Fig. 49, for the materials used in the principal sewage filters at Lawrence. It was found that the finest 10 per cent. of the particles seemed to be of the most significance in recording and comparing the behavior of the sands for purposes of filtration. This has led to the expression "effective size," which means that 10 per cent. by weight of the particles are smaller than the size given. The irregularity in the sizes of the particles has led to another expression "uniformity coefficient," which is of some significance. If all the grains of a mass of sand were of the same size, the coefficient would be unity, but where marked variations take place, the

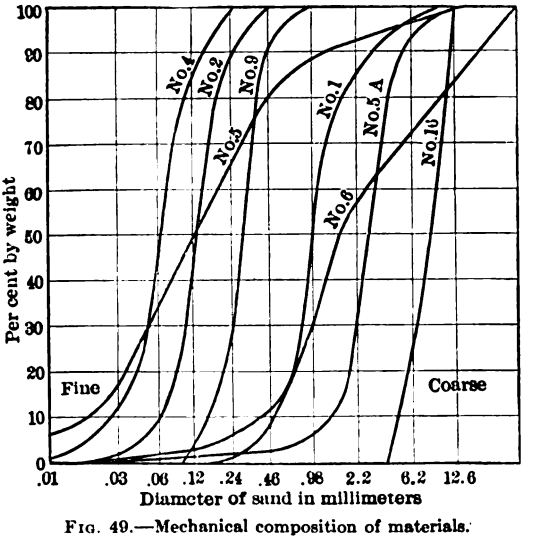


FIG. 49.—Mechanical composition of materials.

practice was developed at Lawrence of regarding the uniformity coefficient as the ratio between the diameter of the particles at the 10 per cent. line and the diameters at the 60 per cent. line. Ordinary mortar sands have a uniformity coefficient between the usual limits of 1.5 and 2.5. Mixtures of gravel and loam give figures far in excess of these.

Air and Water Capacities.—When filter material is perfectly dry and clean, the voids usually range from about 35 to 45 per cent. Naturally they are filled with air. When sewage is applied to filters and the material has been thoroughly drained, it is found that more or less water is retained within the filter material by means of capillarity. With very coarse materials,

such as in gravel filters Nos. 5A and 16 as shown in Fig. 50, from the Lawrence report of 1891, the percentage of the volume of the filter material that is occupied by water is comparatively small. With fine sands, as in the case of filters Nos. 2 and 4, it is noted that the lower portion of the filter has its voids completely occupied with water. With extremely fine material, as in the case of No. 5, it was found that the voids were completely filled with water from the bottom of the filter for a distance of about 4

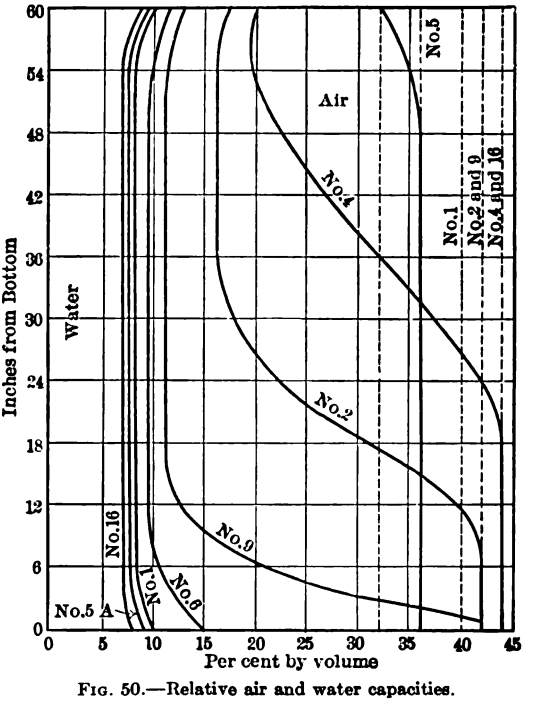


FIG. 50.—Relative air and water capacities.

feet and in the upper foot of the filter there was only a small air space, as shown by the difference between the dotted line and the full line.

Limitations in Dosing.—Bearing in mind that time and atmospheric oxygen are of prime importance in this style of sewage treatment, it follows that attention should be given to the application of the sewage in conformity with the physical character of the material. If the sewage passes too quickly through a coarse gravel filter, in which the water capacity is a comparatively small percentage of the total volume, then it may be said that the

water limit controls the rate at which sewage may be properly applied. On the other hand, with very fine sand and with the lower portion of the filter completely saturated by water held there by capillarity, then it is the amount of air within the interstices which controls the proper dosing of sewage to the filter. Fig. 51 is a sketch from the 1891 Lawrence Report showing that it is the air limit which controls the dosing of very fine material, while for the coarse material it is the limitation in water capacity that controls. If these limitations are not

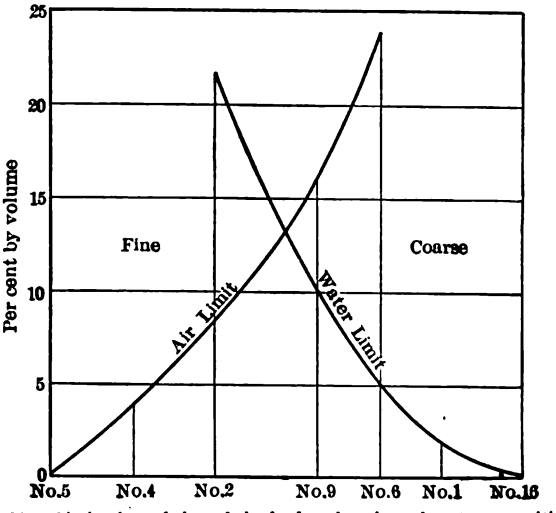


FIG. 51.—Limitation of size of single dose by air and water capacities.

reckoned with, it would soon be found that with a filter of very fine material the capacity might become quickly overtaxed so that clogging would result and a very poor quality of effluent be obtained. For a gravel filter, means must be provided for not having the sewage pass so quickly through the coarse material that the resulting purification will be merely nominal. Reference is made to the early Lawrence reports for further elaboration of these details. Sufficient has been said here to emphasize the importance of proper ventilation in filters at all times and a proper dosing so as to give the bacteria in the presence of air a suitable opportunity of bringing about the desired purification. In fact, contact filters and sprinkling filters in their early days were related considerably to means of improving on a practical working scale the small test devices at Lawrence.

TABLE 88.—AVERAGE DATA OF PRINCIPAL INTERMITTENT SAND FILTERS OPERATED DURING 1888–1902 AT LAWRENCE, ARRANGED TO INDICATE THE DIFFERENCES IN RATE OF FILTRATION AND IN COMPOSITION OF EFFLUENT, DUE TO DIFFERENCES IN KIND OF FILTERING MATERIAL

Sewage and effluents	Filtering material			Years covered by averages	Average number of gallons applied per acre daily for 7 days in the week	Parts per million						Bacteria per cubic centimeter
	Kind	Depth, in inches	Effective size, in millimeters			Oxygen consumed	Nitrogen as Ammonia		Nitrites	Nitrates	Chlorine	
							Albuminoid	Free				
Sewage[1]				1888–1902		39.4	5.77	25.9	0.0	0.0	80.4	2,025,000
Filter No. 1	Coarse sand	63	0.48	1888–1902	61,980	5.8	0.544	5.30	0.215	21.44	81.0	37,500
Filter No. 2	Fine sand	60	0.08	1888–1902	32,184	2.8	0.213	3.53	0.129	21.98	79.0	400
Filter No. 4	River silt with trenches of coarse sand	60	0.04	1888–1902	20,886	2.6	0.206	2.04	0.026	18.90	73.4	200
Filter No. 5a	Gravel	60	1.40	1891–1897	67,422	6.6	0.862	6.10	0.304	21.02	94.4	128,700
Filter No. 6	Mixed gravel and coarse sand	44	0.35	1888–1902	48,618	4.6	0.399	4.58	0.338	21.60	80.0	10,200
Filter No. 7	Same as No. 6, but covered with layer of loam	44	0.35	1888–1894	19,380	1.5	0.154	2.04	0.064	14.37	60.6	1,100
Filter No. 9a	Medium fine sand	60	0.17	1891–1902	58,688	4.8	0.462	7.35	0.099	23.60	85.3	12,400
Filter No. 10	Mixed fine and coarse sand	60	0.35	1894–1902	55,458	4.2	0.400	4.69	0.177	27.80	93.8	6,700

[1] The station sewage gradually grew stronger during this period of 15 years as indicated by the chlorine.

Kinds of Material.—The comparative effect of different kinds of filtering materials, as regards the quantity of sewage treated and the degree of purification, is well illustrated by the results in Table 88 containing the average data for the more important intermittent sand filters which were operated during the years 1888 to 1902, inclusive, at the Lawrence Experiment Station. In general, they correspond with the results obtained from large plants of this type in New England. Attention is particularly directed to the low rates of filtration for those filters containing fine sand or river silt or sand covered with a layer of loam. On the other hand, the quality of effluent is somewhat better from these filters containing fine material than from coarser material.

Depth of Filtering Material.—As to the effect of depth of filtering material, it is to be stated that the majority of work is done by intermittent sand filters at the surface and in the upper 2 or 3 feet. A greater depth than this immediately above the underdrains is desirable, to prevent sewage reaching the effluent pipes before purification is properly effected.

In their review of 21 years' experience with the test filters at Lawrence, Mass., Messrs. Clark and Gage sum up the situation in the 1908 report of the Board, page 302, as follows:

> Taking all things into consideration, the results have shown that while little or no purification can be expected from shallow filters constructed of sand as fine as that of Filters Nos. 2 and 4, yet, with coarser sands, good nitrification will occur in filters not over 2 feet in depth; that the rates must be lower than with deeper filters, and that the unoxidized or partially oxidized organic matter in the effluents of these shallow filters will be large compared with that in the deeper ones. Still, when the organic matter in the applied sewage is considered, good percentage removal of such organic matter is shown. The operation of the filter 10 feet in depth has shown also that increased efficiency is obtained with the greater depth but not enough to be of any considerable importance.
>
> In a general way it can be said that the greater the depth of a sand filter, other things being equal, the greater the degree of purity of its effluent; that with coarse sands, a depth of 4 or 5 feet is desirable, owing to the greater rate that can be maintained with good purification; that with such sands a filter of half this depth can be operated with good results if a lower rate is maintained, that with sands as fine as those of Fliters Nos. 2 and 4, it is necessary, on account of their degree of capillarity, to have a depth sufficient to give an upper unsaturated sand layer in order that air may be introduced. This being provided

for, such a filter will give an effluent of greater purity than the coarser sand filter, but is operated with greater difficulty and requires a much lower rate. Sand slightly coarser than that of Filters Nos. 2 and 4, as instanced by Filters Nos. 140, 141 and 9A, gives, with similar depths, results resembling more the coarser than the finer sands. Depth for depth, they can be operated more nearly as filters of sand as coarse as that of Filters Nos. 1 and 6, rather than as fine as that of Filters Nos. 2 and 4.

This does not quite tell the whole story in connection with practical work, because it does not take into account lateral filtration which is really quite a factor in all sand filters in which gravel underdrains are not placed beneath the entire body of sand. Where filtering material may be availed of in place there is obviously lateral filtration from the surface to the underdrain through which the effluent makes its escape. When the material is porous probably the sand just above and near the underdrains does rather more than its share of the work, but after clogging takes place in part, the entire surface is brought into action and lateral filtration no doubt adds to the purity of the effluent, so that the final result is measurably improved over that which would be obtained if the sewage moved only in a vertical direction as in the case of the well underdrained test filters at Lawrence.

Underdrains.—There is no general rule regarding underdrainage other than that drains should be provided to assist properly in the prompt removal of the sewage from the pores of the filtering material, and thus allow the latter to fill with air. When the ground water reaches within a few feet of the surface, or when artificial beds are built on a fairly impervious bottom, the drains are very important, but they are practically of no benefit where the beds consist of deep natural layers of porous material.

Stratification.—It is of importance in laying out sand filter beds that the materials from top to bottom be fairly uniform in size of grain. If fine sand, loam or clay remains above coarse sand, the latter is of limited benefit for filtration, because a water seal is formed at the bottom of the fine layer, due to the liquid held in the pores by capillarity, and air is excluded from entering the sand. If coarse sand overlies fine material near the surface, clogging sooner or later takes place at the junction and air is similarly excluded.

INFLUENCE OF TEMPERATURE AND COMPOSITON OF SEWAGE UPON NITRIFICATION

In the review which the author prepared in 1894 of seven years' work in testing the behavior of sewage filters at Lawrence, considerable attention was given to the subject indicated by the heading above. All of the filters which had been tested up to the beginning of 1895 were carefully studied to ascertain how long a "pre-nitrification" period was required at different seasons of the year to establish well defined nitrification. A limit was taken arbitrarily which indicated that this preliminary period was terminated when the effluent showed one part per million of nitrogen as nitrates in steadily increasing amounts.

From the above results, which are summarized in the next table (page 476 of 1894 Report of Massachusetts State Board of Health), it was learned that while ten days or less were sufficient in warm weather to allow nitrification to become established, a period of one hundred days or more was necessary in the case of some of the filters started during the winter. It was also learned that the amount of stored nitrogen (more accurately, the difference between the amount applied and that in effluent) in the filters at the end of the pre-nitrification period was in some cases less than five per cent. of what it was in others.

TABLE 89.—SUMMARY OF PRE-NITRIFICATION RESULTS, BY MONTHS

Month	Number of filters started	Average number of days before Nitrates appeared	Average amount of nitrogen per square foot of surface (pounds)			Average temperatures of the effluents (degrees F.)		
			Applied	In effluent	Difference	Maximum	Minimum	Average
January	6	82	.0119	.0022	.0097	44	36	39
February	5	51	.0078	.0009	.0069	46	35	41
March	2	55	.0135	.0085	.0050	60	42	50
April	3	32	.0171	.0057	.0114	55	47	50
May	3	14	.0023	.0005	.0018	64	58	60
June	0							
July	3	9	.0075	.0019	.0056	76	71	73
August	0							
September	1	10	.0184	.0151	.0033	59	55	56
October	0							
November	1	101	.0451	.0240	.0211	46	35	37
December	3	116	.0146	.0035	.0111	47	36	40

The greater portion of the Lawrence filters were started during the colder season of the year. During the period of investigation there were also quite marked variations in the composition of the sewage. To obtain more precise information a series of investigations with small tanks or tubes was undertaken. These tanks, placed in the building, had sewage applied to them at a rate of 120,000 gallons per acre daily for six days in the week. The regular station sewage which is devoid of oxygen was applied in some instances without aeration and in other instances after a current of air had been drawn through the sewage so that it contained as much as 90 per cent. of the oxygen necessary to saturate it at the given temperature. Still other tests were made with fresh sewage from the large Lawrence street sewer before the dissolved oxygen was exhausted by traveling slowly through the 2.5-inch pipe 4300 feet long leading from this sewer to the experiment station. Beginning in June, 1894, a set of experiments was started each month with three of these small tanks: one (I) with the unaerated station sewage; another (II) with aerated station sewage; and a third (III) with fresh sewage from the Lawrence street sewer. These filters, of course, differed from those which were exposed to the weather during the winter months when the temperature of the station buildings was kept moderately high from 5 a. m. to 6 p. m. At night, however, the temperature fell and it was the purpose to guard simply against freezing. The average temperature of the effluents ranged from about 74° F. in summer to 41° in December before the heating system was put into regular service. In January the average temperature was 49°. A table of the results of these pre-nitrification experiments made each month from June to December, inclusive, 1894, is taken from page 478 of the Annual Report of the Massachusetts State Board of Health for 1894, as follows:

TABLE 90.—SUMMARY OF PRE-NITRIFICATION RESULTS FROM MONTHLY SETS OF SPECIAL FILTERS Nos. I, II and III, June to December, inclusive, 1894

Number of filters in the set	Experiment begun	Number of days before nitrification appeared	Amount of nitrogen per square foot of filtering surface in pounds			Temperature of effluent (degrees F.)		
			Applied	In effluent	Difference	Maximum	Minimum	Average
I	June 7	4	.0036	.0004	.0032	79	64	70
II	June 7	4	.0036	.0005	.0031	79	64	70
III	June 7	4	.0023	.0005	.0018	79	64	70
I	July 6	4	.0037	.0002	.0035	77	70	74
II	July 6	4	.0037	.0002	.0035	77	70	74
III	July 6	4	.0037	.0007	.0030	77	70	74
I	Aug. 14	3	.0023	.0002	.0021	75	73	74
II	Aug. 14	2	.0016	.0001	.0015	75	74	74
III	Aug. 14	6	.0040	.0004	.0036	75	72	74
I	Sept. 11	6	.0040	.0002	.0038	69	64	67
II	Sept. 11	6	.0040	.0002	.0038	69	64	67
III	Sept. 11	6	.0038	.0004	.0034	69	64	67
I	Oct. 11	11	.0095	.0007	.0088	61	52	56
II	Oct. 11	11	.0095	.0005	.0090	61	52	56
III	Oct. 11	11	.0072	.0011	.0061	61	52	56
I	Nov. 12	59	.0617	.0225	.0392	52	32	42
II	Nov. 12	59	.0617	.0243	.0374	52	32	42
III	Nov. 12	62	.0506	.0252	.0254	52	32	42
I	Dec. 18	37	.0356	.0115	.0241	50	32	41
II	Dec. 18	44	.0424	.0166	.0258	50	32	41
III	Dec. 18	84	.0533	.0480	.0053	50	32	41
IV	Jan. 9	15	.0140	.0020	.0120	53	45	49

Summary.—The deductions made from these and some corresponding experiments made during the same period may be concisely stated, as follows:

1. Nitrification became established in each case in from two to six days, when the average temperature of the effluent was between 67° and 74°; in eleven days at 56°; and in thirty-seven days or more, when the average temperature was 45° or less.

2. The increase of 3° in the average temperature of the December experiments, owing to improved heating facilities, caused nitrification to appear 15 to 22 days earlier than in the corresponding November experiments.

3. Aeration of the station sewage had no apparent influence in hastening nitrification at any time during the year.

4. Nitrification in Filter III, which received fresh sewage from the Lawrence Street sewer, appeared much more slowly in cold weather than in the case of the other two filters receiving partially decomposed sewage. In warm weather there was only a slight difference, although No. III required a longer time for complete nitrification to become established.

5. During warm weather nitrification under the stated conditions appeared before the capacity of the filtering material to absorb the free ammonia of the applied sewage by chemical means was overtaxed.

6. During warm weather nitrification became practically complete in so short a time that, together with the above-mentioned condition, the effluent of the station sewage contained but little free ammonia at any time. This is also true to a large degree of the effluent of the sewage direct from the Lawrence Street sewer.

7. During cold weather the capacity of the filtering materials to absorb free ammonia in the applied sewage was overtaxed long before nitrification set in, and when it appeared it was not sufficiently complete to prevent comparatively large quantities of free ammonia from being present in the effluents.

8. Nitrification in sewage filters may become established in mid-winter at an average temperature of 50° Fahrenheit in the comparatively short period of sixteen days.

9. Nitrification may be destroyed in a filter which has been drained, by exposure to an average mean temperature of 22° for one week under the conditions applied to Filter IV.

10. Storage of organic matter in filtering materials played a

far less important part in the establishment of nitrification than did temperature, although it is of course necessary to have some food present for the organisms to live upon. From other experiments it appears, however, that the intensity of nitrification depends to a considerable extent upon the storage of organic matter.

11. The time necessary to reestablish nitrification in winter was practically the same as if the filter were new; but whether the organisms were killed by the exposure to the cold, or only affected so that their functions were temporarily interrupted, cannot be stated.

12. A small portion of material containing nitrifying organisms in an active state, when mixed with new sand in a filter, enables nitrification to become well established in three days, even at the comparatively low temperature of 58° Fahrenheit.

13. Long exposure to the cold of material known to be rich in nitrifying organisms during warm weather reduces the activity of these organisms practically to zero, and such material upon mixture with new sand is of little aid in hastening nitrification.

BIOLOGICAL CONSTRUCTION

The expression "period of biological construction" was used in the Lawrence reports some years ago, meaning the period which was required for the establishment of nitrification in new filters, or in those in which it had disappeared. Frequently it happens that the ordinary construction of disposal works is completed late in the autumn, and it is not unnatural that sewage should then be applied to the beds. This is frequently a great disadvantage, in that it clogs the filtering material during quite a number of months prior to the establishment of active nitrification, and seriously handicaps future operations. This same comment holds true with regard to septic treatment, as well as other various kinds of biological filters.

SURFACE CLOGGING

The suspended matters in sewage naturally are retained for the most part at and near the surface of the sand layer, and it is obvious that they would form an almost impervious layer

ultimately if the surface were not freed from such matters. Air would thus be prevented from entering the pores of the material, and the process would be seriously interfered with. Frequent raking and harrowing, and occasional plowing and scraping, are required to remove clogging due to the accumulation of sludge.

Some of this suspended matter is of a mineral nature and it is of course impossible for it to be removed by nitrification. Naturally, this accumulation becomes sufficiently great in time to have the effect of partially closing the voids and making the filtering material similar in character to new material of a much finer size of grain. This is well shown by the reports from Lawrence, which state that in 1902 the upper 6 inches of Filter I, after 15 years' service had an effective size of 0.30 millimeter as compared with 0.48 millimeter when the sand was new. Below 9 inches from the surface this sand was then of the original grade.

No matter how low the rate of filtration may be, it seems obvious from a theoretical standpoint that suspended mineral matters and humus will ultimately require the removal of the surface layer of all sand filters. It seems probable, if not certain, that in the long run the amount of material to be removed (independent of the rate of filtration) bears a definite relation to the quantity of suspended matter applied to the filter bed. The quantity of sand removed per million gallons increases quite rapidly with the rate of filtration, other things being equal.

The evidence upon this matter is considerably obscured by clogging and changes in the sand layer below the depths reached by the frequent rakings. It is also complicated by differences in the character of the sewage, the full significance of which is not now understood.

As a practical proposition this question is quite intimately related to a balancing of the total cost of two procedures. First, with low rates where is comparatively little clogging of the surface of intermittent sand filters if care is taken to remove by raking or harrowing some of the coarser matters which seem to form a mat or film on the surface; and secondly, with high rates where surface clogging rapidly becomes a factor. It doubtless makes considerable difference whether the sewage receives the mineral matter from street washing entering combined sewers or whether the applied sewage is wholly of domestic origin. Within the

past few years careful studies made at the Lawrence Experiment Station indicate that bacterial action is capable of oxidizing and removing more of the stable organic matters than was thought practicable a few years ago. In this connection the comments of Messrs. Clark and Gage as given on page 328 of their 1908 Report are of interest, as follows:

> The work upon the removal of organic matter seems to show clearly that by systematic resting of the upper sand of sewage filters a considerable percentage of the nitrogenous organic matter may be, in some instances, removed by bacterial action. Still, when such filters have been in use for many years, and the accumulated organic matter has undergone this long-continued bacterial action that is always taking place in such filters, most of this matter is found to be stable in nature and difficult to oxidize. Undoubtedly a certain portion of it is as stable as humus; in other words, as stable as soil nitrogen which remains year after year at practically the same point unless exhausted by severe cropping. It is the residual organic matter remaining after the easily changed matter has been removed by bacterial action. Notwithstanding this accumulation of stable matter it has been possible to keep Filters Nos. 1, 2, 4 and 6 in operation for 21 years without sand removal, except in 1892 and 1893, and, judging from the condition of the filters at present, satisfactory operation for a number of years without further removal of surface sand is possible and probable. It was predicted in the report for 1904 that some of this stored organic matter would become in the course of time more easily oxidized, and the large amount of oxidized nitrogen in the 1907–1908 effluents would seem to show this to be the fact.

In closing this topic it is perhaps needless to say that surface clogging should be well guarded against. This relates during the summer months to freeing the surface of weeds and algæ growths if such should appear on the surface of the liquid which may stand for some time on the surface of the sand. A number of years ago the intermittent sand filters at Pawtucket, R. I., were interrupted in their normal service by growths of microscopic organisms which were eliminated in considerable measure with the use of copper sulphate. In winter when it is not feasible for some weeks or months regularly to rake, plow or scrape filters, it is necessary to keep the dose as well adjusted as practicable to the capacity of the beds after putting them in good condition before cold weather sets in.

WINTER TREATMENT

During the long cold winters of the northern section of this country, intermittent sand filters have to be operated with considerable judgment in order that their efficiency is not impaired seriously. At best the quality of the effluent is somewhat poorer in winter than during warm weather (see Lawrence Report, 1894, page 513). Speaking generally, it has been found in practice that it is less difficult to maintain the surface of filter beds sufficiently free from frost so as to allow the sewage to enter them, than was first indicated by the test filters at Lawrence. To accomplish this, however, it is necessary to apply the sewage in relatively large doses, thus concentrating a sufficient amount of heat to penetrate the frost. Assistance has also been obtained at some places by arranging the surfaces of the filter beds in alternate ridges and furrows or piles. As many weeks go by without opportunity to remove any sludge from the trenches, there is a limit to the total quantity of sewage which can be so applied. Ice which forms upon the surface of the sewage may rest upon the ridges, thus forming a natural covering over the portion of the area which actually receives most of the sewage. Especially do the ridges or piles aid in preventing the ice from becoming attached to the major portion of the filtering surface.

Intermittent sand filters work to least advantage in the late winter or early spring when the surface clogging representing the winter accumulations has not been removed. In some instances the filters become seriously clogged so that the applied sewage tops the banks surrounding the beds and overflows to the nearest stream. When warm weather suddenly appears it is not infrequent that these pools of sewage on the clogged beds "putrefy" and give off more or less odor before it is possible to get the beds into good working condition again.

Brockton Data.—This whole question of maintenance of sewage filters in winter was quite thoroughly exploited in a paper on this topic read in December, 1906, before the Sanitary Section of the Boston Society of Civil Engineers by Mr. George E. Bolling of Brockton, Mass. The Brockton filters were put in service in November, 1894, and the rapidly growing city has caused the plant to be extended after encountering complications as to clogging in a degree not found at most other places. This paper of Mr. Bolling's and the discussions upon it by those

in charge of other important sand filter plants in Massachusetts constitutes the best evidence available on this subject. Use will be made freely of this paper which appears in Vol. XXXVIII of the *Journal of the Association of Engineering Societies.* It begins with reference to the effect which frost has on level beds as given in the Annual Report for 1894 of Mr. F. Herbert Snow, the City Engineer of Brockton, Mass., who wrote as follows:

Considerable ice began to form early in December, 1894, around the edges of the level beds, and gradually to approach the carriers. The temperature of the sewage, at this time about 44° Fahr., was readily chilled by the snow to a point where it had little power to melt the ice. Observations, made while putting sewage into snow, showed the temperature to be: in the pipe 45° Fahr.; 20 feet away from the carrier, 43°; 50 feet, 42°; 75 feet, 37°; and beyond this the sewage did not penetrate the snow at all. Within this area the liquid retained in the upper inches of the filter by the accumulated organic matter froze solid. At a greater depth than 2 inches, less liquid being retained by the sand grains, though frozen, the mass remained porous. If there had been warmth enough in the applied sewage to thaw the upper layers it would readily have passed through the lower porous, though frozen, sands. But it is easy to understand how the sewage flowing in a thin sheet became chilled by the ice and snow to a point where it could not thaw its way through the upper frozen layer, thus rendering the level beds entirely useless until warmer weather.

In about four years it became necessary to use all of the 23 filter beds during the winter months and for some time it was the practice to furrow each bed each fall in preparation for the coming winter. Fig. 52 shows a view of these filters as taken by Mr. Pearse. Mr. Bolling describes that treatment, as follows:

As first practised in preparing to furrow a bed, it was first plowed and harrowed, and then furrowed, but it was found on trying the experiment that unless a bed had had considerable heavy teaming done over its surface and the soil was packed down hard, the preliminary plowing and harrowing could be dispensed with, and the flat bed furrowed directly into ridges, thus saving the extra item of expense.

In making the furrows we use a common Ames No. 1 double-moldboard plow, with an extra iron form attached to the moldboard, which enables a deeper cut to be made, and the flaring edges round over the shoulders of the ridges, leaving less loose material to fall or be washed down into the furrows.

At present, the beds are prepared for winter use with the tops of the ridges about 3 feet apart, and the furrows about 12 inches in depth.

It is found after a bed is newly furrowed that, for the first four or five doses applied, material from the sides of the ridges will be washed down into the bottom of the furrows, but after the fourth or fifth dose very little is washed down. This washing of the material down into the trenches is of no particular moment except in case of the sludge beds where alternate layers of sludge and sand are deposited, necessitating the removal of considerable of the filtering material when the beds are cleaned in the spring. It is customary with us to dose a newly-furrowed bed that is to receive sludge during the winter with one or two preliminary doses of the lighter sewage, as it is in the first one or two doses that the most of the loose material of the sides of the ridges is washed down into the trench.

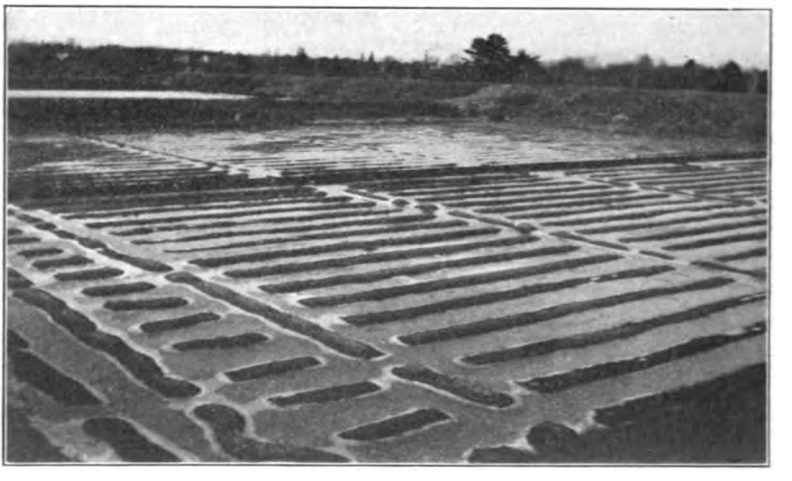


FIG. 52.—Brockton filters showing winter furrows.

The one great object to be accomplished by furrowing a bed for winter use is, of course, to keep the ice, which in this latitude is certain to form in an ordinary winter, from attaching itself to the whole surface of the filter.

In our experience, frost cannot be kept out of the trenches; in fact in a winter of ordinary severity the frost penetrates down into the bed 8 or 10 inches below the bottom of the trenches. This frost line in a way is comparable with a water table, in that it conforms to the configuration of the surface of the ground, and while almost the entire ridge may be frozen solid and the frost have penetrated down into the bed nearly a foot below the bottom of the trenches, the unfrozen sand under the ridges is nearer the sewage when it is applied than is that directly under the furrow. Therefore, the sewage when flow-

ing in the trenches of a furrowed bed exposes less surface to the cold and has its warmth conserved while thawing through the frost to the more porous sand. It is our experience that as the strength of our sewage has increased and the amount of sediment deposited in the trenches has become consequently greater, presenting an almost impervious layer to the applied sewage, much of the absorption into the body of the filter takes place diagonally downward through the sides of the ridges.

On the application of a dose of sewage to a furrowed bed in the winter absorption does not take place until the warmth of the sewage has thawed out a way for itself along the path of the least resistance. While this is occurring and there is no settling of the sewage a sheet of ice forms on the top, and when subsidence is finally effected this ice is left supported by the tops of the ridges, affording an additional help in conserving the heat of the additional doses applied to the bed.

Bearing in mind the necessity of having ample oxygen in order to obtain efficient purification, it is quite evident that the Brockton beds as well as most other sand filter beds deteriorate more or less during the late winter and early spring before the beds can be freed of winter clogging, as has been already indicated above. On the question of quality of effluent and the cost of treatment, the statements of Mr. Bolling are interesting, as follows:

Many of the winter effluents, while appearing only slightly turbid at time of collection, after standing in the laboratory a short time begin to deposit a copious precipitate of iron which renders them very unsightly. This iron is derived from the soil of the filter beds and its solution in the effluent is facilitated by the amount of organic matter the winter effluents contain. Effluents carrying as much iron as 12 parts per 100,000 parts are not uncommon in the winter. The quality of the effluent improving as the summer advances, the iron gradually grows less in amount and finally ceases to be apparent.

It may be asked why, if this standing of sewage to a depth of, in some cases, 18 inches upon the beds is to be a regular occurrence each winter, there is any advantage in furrowing the beds at all. We believe that, if it were not done and continued cold weather should ensue before the sewage had reached is winter height, there would be a possibility of ice forming and attaching itself to the entire surface of the bed which would then, of course, throw the bed out of use for the rest of the winter.

As regards the relative cost of having the filters furrowed and leaving them level, there is not much to choose between the two.

The average cost of furrowing an acre bed is $3.30, and of shoveling the outlets from the carrier through the ridges so as to permit the distribution of the sewage over the bed is $1.91, a total of $5.21.

If the bed were left level for winter use we should consider it advisable to first plow and harrow it on account of the amount of teaming done over it during the summer; this would cost $4.17 for plowing and $1.02 for harrowing, a total of $5.19.

The item where expense might be saved is the greater ease in cleaning a flat bed. The average number of loads of sediment and dirty sand removed from a furrowed bed in the spring is from 200 to 400. On a flat bed this sediment could be gathered up without taking anything like as much of the filter material with it.

But here the question presents itself: Is not the furrowed bed all the better off on account of having so much of the material with a tendency to clog removed from it?

Clinton Data.—The discussion by Mr. E. R. B. Allardice of the Clinton, Mass. sewage disposal works, is of interest in indicating that a portion of the beds at that plant are furrowed for use during very cold weather and that the remaining beds without furrowing are operated when the weather is above 15° Fahrenheit at 7 a. m. Attention is also directed to difficulties encountered in applying sewage when there is deep snow on the beds. His statement in full is as follows:

The Clinton sewage disposal plant was built and is maintained by the Metropolitan Water and Sewerage Board. It comprises eight settling tanks and about 25 acres of filtering area, divided into beds of about one acre each. In the fall of the year, just previous to the time when freezing takes place, five of these 25 beds are furrowed. The sewage is delivered to these beds from an inlet which is placed at the middle of one side, and to carry the sewage directly across the bed three main channels are dug, which divide the bed into four equal parts. Then at right angles to these three main channels there are furrows similar to those described by Mr. Bolling, the furrows being 3.5 feet apart and 15 inches deep. Previous to this work in the fall the bed is given a complete cleaning by raking up any scum or sediment which has formed on the surface during the summer. The sewage is applied to the furrowed beds at such times as the temperature at 7 o'clock in the morning is below 15° Fahrenheit. When the temperature is higher the flat beds operate satisfactorily.

The furrowed beds are given doses which range from 500,000 gallons per acre upward. The dose is sufficient to flood the bed to a depth of more than a foot above the ridges, and, before it has seeped away, a

coating of ice some 2 inches in thickness has formed, so that when the sewage has entirely disappeared this rests on the tops of the furrows, thus protecting the bottom, which we find has never become frozen, always being soft and ready to carry away the sewage at the time of the next application. When the temperature is higher than 15° Fahrenheit we apply the sewage to flat beds in doses of 250,000 gallons per acre. This we find can be done at all times, unless there is deep snow on the bed. At these times we plow furrows in the snow, about ten feet apart, thus allowing the sewage to reach the far points as quickly as possible. But, unfortunately, this method of applying sewage has not been entirely satisfactory, the sewage becoming so chilled that a heavy coating of ice forms on the beds, and unless we have a few days of moderate weather the bed will be forced out of commission.

In the spring of the year, when the freezing weather has passed by, we find that there is sediment in the bottom of the furrows from 4 to 6 inches deep, and this has to be cleaned out and carted off. We usually get from 275 to 300 loads from each bed. The quantity of solid matter has been greatly reduced by passing the sewage through settling tanks, which were built in the fall of 1904. The sewage is allowed to pass through one tank for two weeks at a time, and since they have been put in operation, which was only last year, we have not been compelled to clean the bottom of the furrows in the spring, the settling tanks taking care of almost all of the sludge which was in the sewage.

Framingham Data.—At Framingham, Mass., there is an intermittent sand filter plant which has given excellent results for more than 20 years and without much difficulty as to operation. This is due in considerable measure to having an ample area of deep porous material that has been operated at a comparatively low rate of filtration. Indeed, the rate is so low that it has been feasible for many years to plant corn and get a ridged-surface effect in this way. The statement of Mr. E. C. Frost concerning the Framingham beds is in full as follows:

Many reports have been made public explaining the methods employed in preparing the filter beds at Framingham, therefore, it would avail nothing to describe them in detail here. Suffice it to say that the loam was removed, the beds graded, the cuts making the fill in many places, and in no instance was a filter wholly made of foreign material.

From the foregoing we can understand why it is that no two beds at Framingham are of the same character and they, therefore, cannot be treated the same, some being of much looser material than others and differently drained; therefore, we can have no fixed rule for flooding our beds unless it be "moderation" and "eternal vigilance."

We prepare the filters each spring by raking and removing sludge, plowing, and planting Indian corn in hills 3 feet apart each way. A hill about 5 inches high is made around the stocks, which are cut each fall about 5 inches higher than the surface of the hill.

In flooding beds in winter I consider it one of the vital points to cover them quickly and to a greater depth than in summer. My reason for so doing is that, provided freezing weather prevails, the ice forms well up on the hills and there rests until melted away by warm rains which, of course, put your filter in good condition again. Should the weather continue cold, be sure to flood the bed as quickly as possible, thereby melting a larger amount of ice than would be melted by running slowly. In this way the bed can be kept open a much longer time. The above method is carried out if we have a fall of snow when no ice protects the surface of the filter and for the same reasons.

A great mistake can be made if one should try to keep open too much filtering surface with a given amount of sewage during a continued "cold snap." After having learned the amount of sewage each bed is capable of handling satisfactorily it is then easy to determine how many beds are required to filter your supply, but a mistake can also be made by not starting with enough. I always prefer to start with more than enough and keep as many of them in good working order as possible, and if I get a few warm days I always open up another filter or two, perhaps resting some that have had all they can do for a long time. Ordinarily there are sufficient warm spells or "thaws" during each winter of sufficient duration to enable me to open up others, so that practically all of our filters get their share.

Worcester Data.—At Worcester, Mass., the sewage is mixed with considerable quantities of trade wastes of various kinds, particularly pickling liquors from steel works. The sewage first passes through a small grit chamber, and a portion of the strongest sewage is applied to sand filters which are not furrowed. They are aided, however, in the prevention of ice attaching to the surface by allowing accumulations of sand scraped from the surface to remain in piles during the winter. The statement of Mr. H. P. Eddy, formerly for many years superintendent of sewers of Worcester, is particularly interesting in explaining a different viewpoint from that held by some others, as follows:

The reason we do not use the furrowed bed is because, in the first place, it costs something to furrow it. In the second place, running the crude sewage on, as we do, without any removal of suspended matter, except that taken out in the grit chamber, 0.3 cubic yard per million gallons, would give an immense accumulation of sludge in the furrows and put

the bed out of business. In the spring, when we clean the bed, it costs a great deal more to get the sludge out of the furrows than it would to remove it from the flat bed. In the third place, every time the surface of the bed is disturbed it mixes the organic matter which is in the sand and is not completely removed in cleaning with the comparatively clean sand below. I appreciate that all of these reasons are subject to discussion and differences of opinion, but my judgment is that the reason we have differences of opinion is largely because of differences in local conditions. We get, as a rule, more water through our filters in winter than in summer, which is another point on which we do not all agree, perhaps. But my impression is that the reason for that in our case is that we do not allow the frost to form to any great depth; perhaps 6 inches would be our limit, and that has certainly the effect of expanding the surface. The frost pushes the grains of sand on the surface, which are mixed more or less with organic matter, further apart and this lets the water through more easily. When the temperature is such that the surface of the bed is just frozen hard enough to drive a team on, without cutting through, the bed is very porous and will take a very large amount of water, and we usually avail ourselves of that opportunity to give it a pretty good-sized dose, 300,000 gallons, I should say, to the acre, and in that way get rid of all the frost, and if there is an accumulation of snow, we get rid of that, or most of it, in one or two days. This disposes of the trouble from frost in the bed, which I classify as a different disease from the trouble with ice. The ice which forms on the surface of the bed, before the water penetrates through the sand, settles down, of course, as the water goes into the filter, and if there are no furrows to hold it up there is a tendency for it to freeze to the surface of the bed. To prevent this we rake the sludge on the surface of the beds into piles in the fall of the year, piles, I should say, about 6 inches high and approximately 12 inches in diameter and about 8 feet from center to center. These piles serve to hold this layer of ice off the sand and to prevent it from freezing on to the surface of the bed, and with that assistance we have had practically no trouble from the ice freezing to the surface of the beds on those beds where sewage is distributed from four different points. This, I think, is a very important point to be considered in designing a filtering plant, to deliver the sewage from at least four points, and at the same time not so many points that it is delivered slowly and cools rapidly. The question of keeping the bed free from the suspended matter of the sewage in the winter time is a somewhat troublesome problem, and that we deal with by putting a force of men at work just the minute there is an opportunity—that is, just the minute the weather conditions are right. We are favorably situated in this respect by having a force of men near by on another part of the work, and we simply shut down our filter-pressing plant and send the men down there for perhaps a couple

of hours in the day, and in that way we are able to rake up the coarse material at such points as may be necessary almost every winter. That enables us to keep our filter fairly open and in good condition. These

FIG. 53.—Worcester filters.

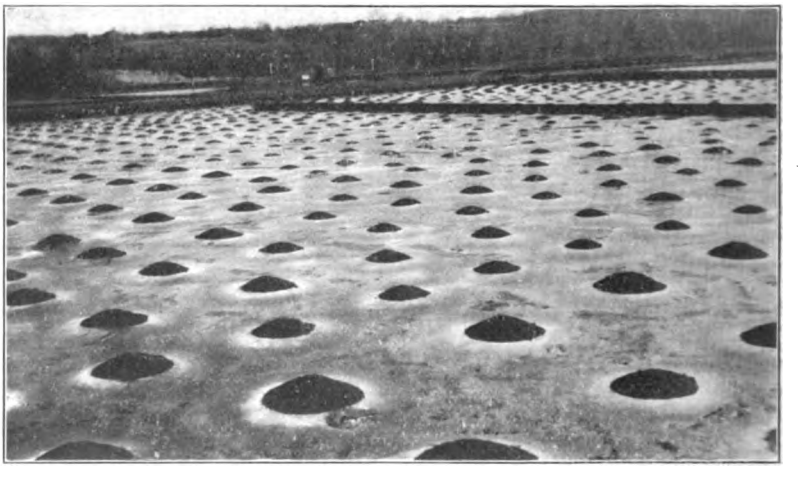


FIG. 54.—Worcester filters.

piles grow in the winter time due to that cleaning, so that in the spring we have 300 cubic yards of material per acre to remove from the filters.

Figs. 53 and 54 are views of the Worcester filters furnished

through the courtesy of Mr. Pearse showing these piles with ice and different quantities of sewage on the beds.

TRADE WASTES

Fairly small quantities of trade wastes in domestic sewage do not seriously interfere with purification by this type of filter. Excessive quantities of trade wastes, however, make serious difficulties, involving much expense both in the construction and operation in comparison with the treatment of ordinary sewage. There is no well-defined rule by which reasonable allowance may be made in advance for the effect of substantial percentages of trade wastes of various kinds in connection with intermittent sand filters. A good clue of what may be expected is to be found in a report by Mr. Clark in the Massachusetts State Board of Health Report for 1909, pages 339–403. This report is practically a summary of 15 years' work at the Lawrence Experiment Station and at various industrial establishments in Massachusetts in treating 15 to 20 different kinds of trade wastes.

At Worcester, Mass., the sewage at times is quite highly impregnated with iron liquors coming from wire works and other iron working establishments. The monthly average results of analyses of daily samples for the year ending November, 1910, show that the sewage covering the sand beds contained about 50 parts of iron per million and that the effluent from the sand filters contained practically half this quantity when the rate of filtration averaged about 73,000 gallons per acre daily. This iron, of course, detracts markedly from the appearance of the effluent at times and shows itself partly by surface clogging and partly by the precipitation in the lower portion of the bed, thus clogging the underdrains. This sewage applied to the Worcester sand beds is the strongest sewage of the day and in 1910 it was first settled in basins having a period of about 30 minutes' average flow. The deposit removed from the surface of the sand beds amounted to about 265 cubic yards per acre annually, or 10 cubic yards per million gallons of sewage filtered in 1910, according to the report of Mr. Matthew Gault, the present Superintendent of Sewers. The cost of cleaning the filter surface is about $0.274 per cubic yard. The seriousness of the clogging of the underdrains may be appreciated by the fact that on 9

one-acre beds it was necessary to spend about $5070 in placing new underdrains.

The Thirty-first Report of the State Board of Health of Connecticut for the two years ending Sept. 30, 1910, contains a number of interesting comments as to difficulties added to the operation of intermittent sand filters due to trade wastes. They refer particularly to iron wastes at Bristol and New Britian and to the silk wastes at South Manchester. At the latter place the area of the sand beds is probably small, but the wastes from silk works clog the surface so that no attempt is made to operate the beds during the winter.

At Westborough, Mass., serious clogging of the sand beds resulted from the discharge into the sewers of waste products from a yeast factory. One of the most striking cases of disturbance of a well-built sand filter plant was that experienced at Hudson, Mass., from the wastes of a wool-washing establishment. In less than two months six acres of filters became so clogged that they could not properly dispose of 200,000 gallons daily. The wastes were removed from the sewers and treated at the mills. After a time the old filters recovered their efficiency as stated in a paper by Mr. Frank A. Barbour in the *Journal of the Association of Engineering Societies* for August, 1911.

At Shelby, Ohio, pickling liquors from iron works have given trouble and led in 1906 to advice from the State Board of Health to the village to have the tube works disconnected from the sewer system. The waste products of the tube works are treated now before the wastes enter the sewers and improved results were noted. The problem at the works was studied coöperatively by the Ohio State Board of Health and the United States Geological Survey. (See Water Supply and Irrigation Paper No. 186, United States Geological Survey.)

METHODS OF DISTRIBUTION

There are numerous arrangements for the application and distribution of sewage over intermittent sand filters. The size of plant, the style of treatment and the use or not of automatic dosing devices has much bearing upon this question. This will be appreciated from what has already been said by different men in charge of important filter plants in New England under the heading "Winter Treatment."

One of the important points in successful operation of intermittent filters is the application of the sewage at such a rate that the filter surface will be quickly covered with sewage. Otherwise that part of the filter adjoining the distributors will be overworked, while the part some distance away may receive but little or no sewage. In large plants this point is taken care of by the ordinary high rate of application. This is especially so at some of the Massachusetts plants where the sewage is applied to the filters for only 8 hours each day, so that the actual rate of application is approximately three times the normal rate of sewage flow. At Pittsfield the rate of application is such that a one-acre filter is given its proper dose of sewage of 100,000 gallons in 20 minutes. Dosing devices for plants of this size would be cumbersome and increase unnecessarily the expense of construction without adding to the ease or efficiency of operation.

For small plants, particularly institutional plants, where attendants are not regularly available, there is undoubtedly much to recommend in the automatic dosing devices. They are spoken of very highly by the engineers of the Ohio State Board of Health in their report of 1908. For large sand filters the variations in treatment as to quantity of dose, particularly with varying temperature conditions in winter, lead the author to feel that automatic dosing is less desirable than in the case of small sand filters, or of large filters of either the contact type or sprinkling type.

Fig. 55, furnished through the courtesy of the Pacific Flush Tank Co., show the general arrangement and details of the dosing devices for the intermittent sand filter plant at Hempstead, L. I. The total area of filtering surface is 3.5 acres and the alternation of the application of sewage to each bed in rotation is accomplished by means of five 14-inch Miller siphons. These siphons are set to draw 4 feet of liquid and are of a capacity sufficient to handle a maximum 24-hour inflow of one million gallons each and also to operate under a minimum daily flow of 300,000 gallons. Each siphon is connected to a separate sand bed with bypasses so that the 10 beds may be used with five siphons. Each siphon, as it discharges, draws down the liquid in the dosing chamber and in the tile well immediately behind the siphon operating it. When the tank again fills the starting bell in this well, which has been emptied, is the only

one of the five to compress air. The air compressed in this starting bell is carried upward and across to the blowoff trap standing alongside the siphon next to be started. There are three-way cutoff valves in the horizontal piping by means of which the compressed air can be transmitted to any desired

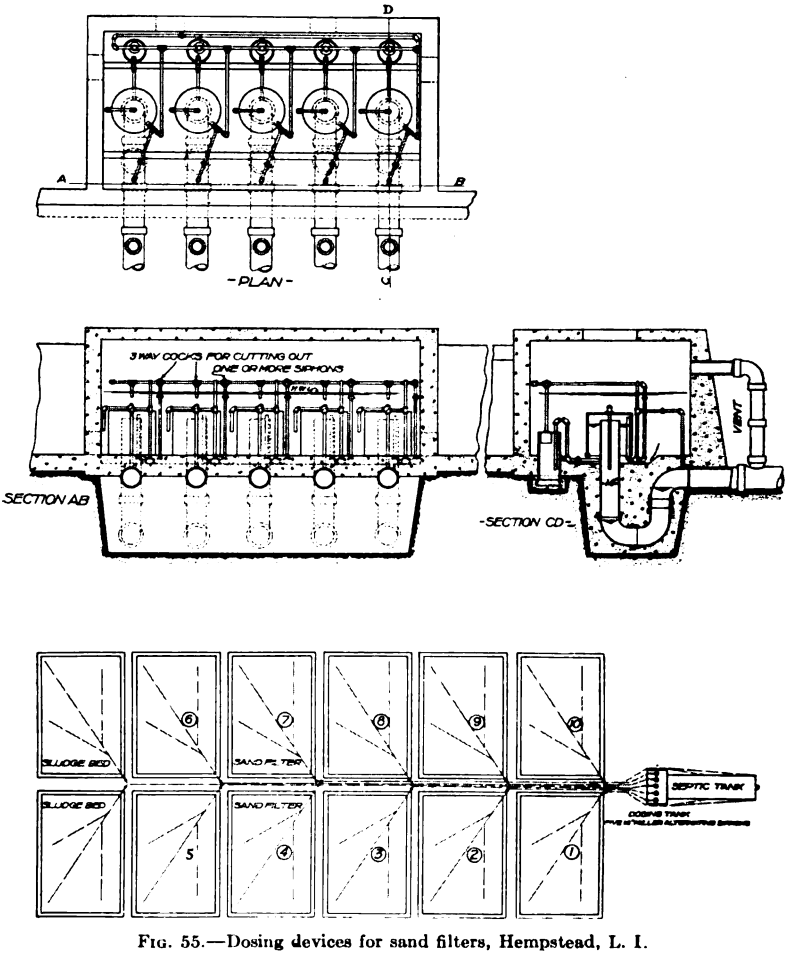


FIG. 55.—Dosing devices for sand filters, Hempstead, L. I.

siphon, the ones thereby skipped remaining out of commission and the others working automatically. This is believed to be the largest set of five plural alternating siphons in the United States.

Fig. 56, furnished by the courtesy of Mr. Potts, shows a

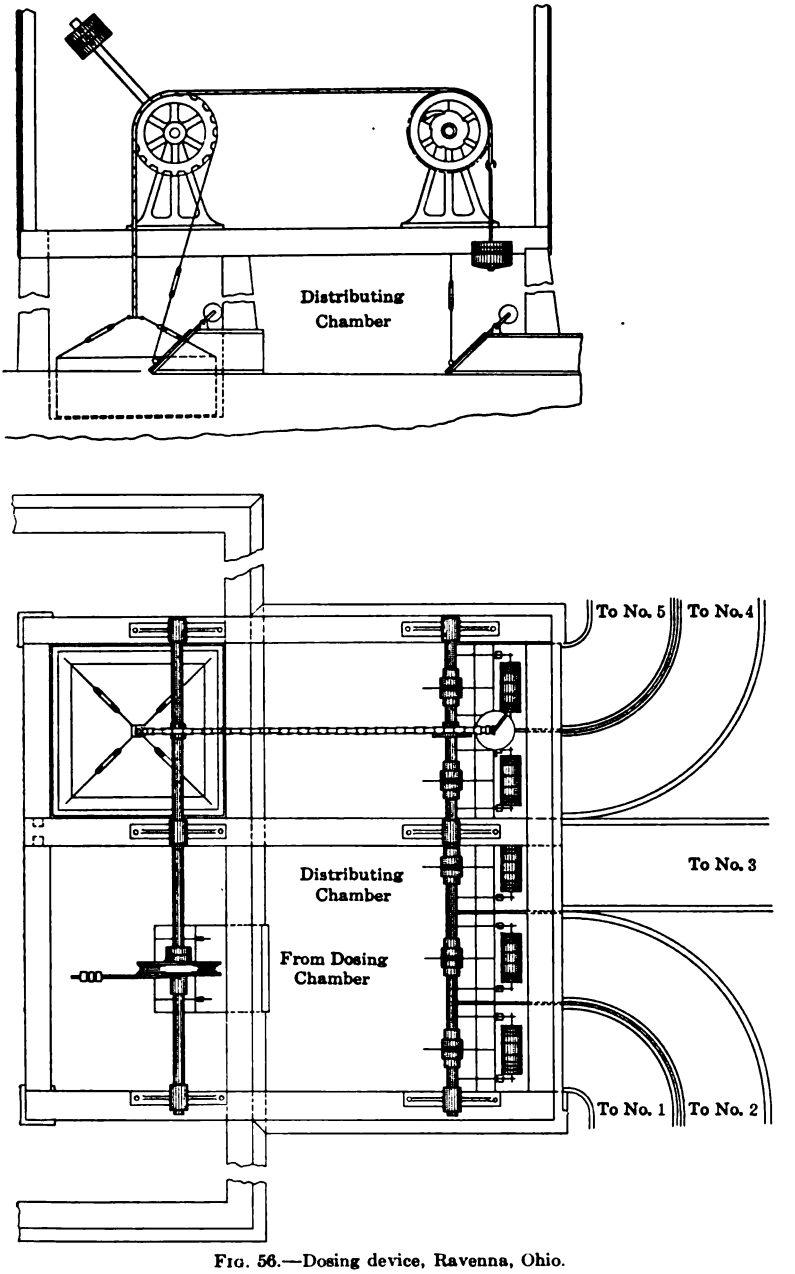


FIG. 56.—Dosing device, Ravenna, Ohio.

device used at Ravenna, Ohio, by Messrs. Williams, Proctor & Potts for dosing the intermittent sand filters at that place. The device is similar to that now manufactured by the Ansonia Mfg. Co. As shown on the plan view the sewage is stored in a chamber from which it is admitted to the distribution chamber by a flap valve and from the distribution chamber it flows through other flap valves to the filters in rotation. The operation is as follows:

As the sewage rises in the dosing chamber it lifts a large float and with it the weighted arm attached to the horizontal shaft.

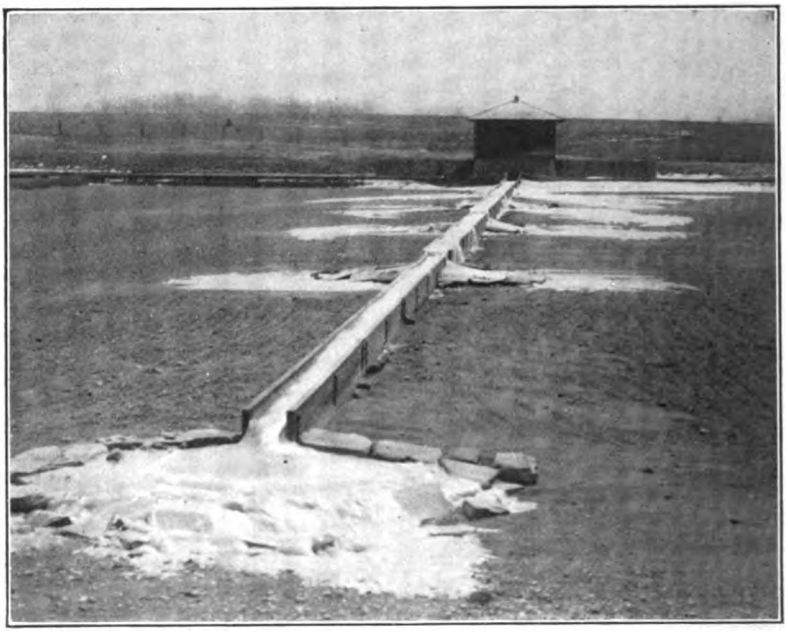


FIG. 57.—Dosing trough, Ravenna, Ohio.

At a predetermined height this weighted arm falls and opens the valve leading to the distribution chamber. The movement of the float which operates this inlet valve is communicated to a second shaft by means of sprocket wheels and chain, and the gates leading to the filters are opened in rotation.

Fig. 57 shows the method of distributing the sewage on to the filters at the same plant.

Fig. 58 shows an ingenious and simple device as installed by Mr. John W. Alvord at Lake Forest, Ill. The device as

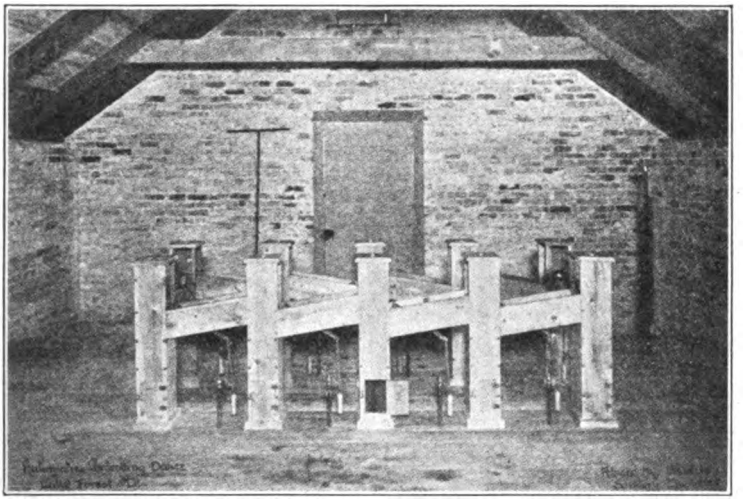


FIG. 58.—Dosing device, Lake Forest, Ill.

FIG. 59.—Distributing trough, Lake Forest, Ill.

shown in the picture rests on the floor above the dosing chamber. There is a float in this dosing chamber which as the sewage rises operates an arm in each of the small wooden columns shown in the figure and lifts an iron ball in one of the columns. As the float reaches a certain elevation the ball rolls from one column to the next through the passage connecting the columns and in its passage engages a lug which actuates an air valve attached to the 10-inch siphon which it is desired to use, in the dosing chamber. The filters are thus dosed in rotation. Fig. 59 shows the arrangement for distributing the sewage on the

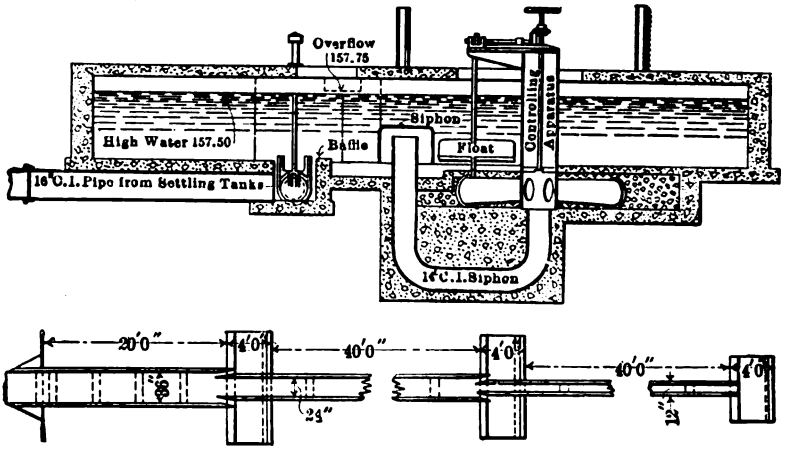


FIG. 60.—Dosing device and trough distributor, North Attleboro, Mass.

beds. These distributors are wooden troughs, rectangular in cross-section and of 2-inch plank, with 3-inch holes spaced 2 feet apart at the bottom of the upright sides.

At North Attleboro, Mass., Mr. Barbour has arranged ingenious devices both for dosing the sand filters and for distributing the sewage on them. The dosing device and distributor are shown on Fig. 60 through the courtesy of Mr. Barbour. The dosing device, consisting of a 14-inch Miller siphon with controlling apparatus, is placed in a concrete dosing chamber about 24 by 32 feet in size. The operation of this device is quite simple. As the sewage rises in the dosing chamber the float of the controlling apparatus rises and by means of beveled gears turns the revolving gate in the cylinder so that

the opening in the gate comes opposite one of the four pipes leading to the sand filters. When the sewage in the chamber reaches a determined height a second float operates an air outlet on the siphon bell, releasing the air and allowing the siphon to discharge. As the sewage falls in the dosing chamber the air inlet to the siphon bell closes and the operating float drops to its lower position. The amount of dose can be changed by varying the height of the float which controls the escape of air from the siphon bell. This dosing apparatus is similar to that installed by Mr. Barbour at Saratoga Springs.

The distributors are in the form of rectangular wooden troughs about 12 inches high and decreasing from 36 inches wide to 12 inches, as shown on the illustration.

ODORS

Where well-designed plants have been intelligently operated intermittent sand filters have ordinarily given results with respect to odors that are satisfactory to State Boards of Health.

At Roland Park, on the outskirts of Baltimore, a sand filter plant was designed by Messrs. Hering & Fuller in 1901. The sewage of more than 3000 people is here applied to sand beds having an aggregate area of about 3.5 acres. One and frequently two men are in regular attendance and the accumulations of deposits on the surface of the beds are removed after each dose. The beds are kept ridged throughout the year and the single doses are larger than are applied ordinarily to sand beds elsewhere. These beds, as shown in Fig. 61, by courtesy of Mr. Richard W. Marchant, Jr., adjoin the tracks of the Northern Central Railroad and a teeing ground of one of the principal golf clubs of that vicinity. No trouble has been experienced from odors.

In 1895 the city of Plainfield built a sand filter plant for the treatment of its sewage. The area of the beds was liberal, but the filtering material was very fine. Consequently the sand surfaces soon became overloaded with the result that the sewage remained upon the beds and "putrefied." Threatened litigation from neighboring property owners caused the abandonment of these intermittent filters and the substitution therefor of septic tanks and contact beds in 1901.

Intermittent sand filters of good porous material it overloaded or if the surfaces are not kept in a porous condition may give trouble. This is particularly true in some places in the early spring where accumulations of sludge during the winter cause pooling and putrefaction before the beds may be put in good shape.

Between the conditions resulting from the excellent operation at Roland Park and the pooling which was unavoidably encoun-

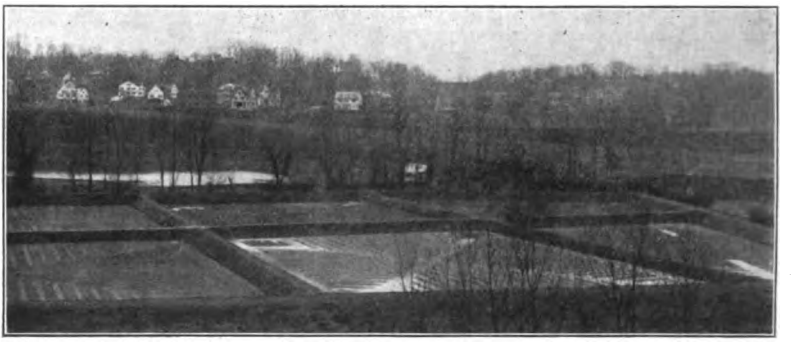


FIG. 61.—Sand filter, Roland Park, Md.

tered with the fine material at Plainfield there is a very wide range of intermediate conditions which are dependent upon the nature of the material, the load applied to the beds and the care with which they are operated.

Quite a number of important sand filters are located fairly close to frequently-traveled roads, although usually it is the intention to have them somewhat isolated if this is feasible.

COST OF CONSTRUCTION AND OPERATION OF INTERMITTENT SAND FILTERS

The expense of purifying sewage in intermittent sand filters depends upon a wide variety of local conditions. A good outline of cost for general purposes of reference is obtained from the data in the Report of the Massachusetts State Board of Health for 1903, page 452, as given in Tables 91 and 92:

TABLE 91.—COST OF MASSACHUSETTS SAND FILTERS

City or town	Area of filter beds (acres)	Cost of filter beds	Cost per acre	Total cost of purification works
Andover	3.80	$17,649	$4,644	$22,157
Brockton	21.48	50,302	2,342	208,977
Clinton	23.50	21,163	900	104,673
Concord	3.30	2,600	788	48,845
Framingham	19.9	10,000	503	76,495
Gardner (Gardner system)	2.67	18,850	7,060	24,799
Gardner (Templeton system)	2.25	11,253	5,001	36,898
Leicester	0.36	2,389	6,636	.....
Marlborough	11.92	31,517[1]	2,644[1]	34,517
Natick	11.10	23,500	2,117	87,000
Pittsfield	24.78	30,000	1,211	155,500
Southbridge	7.25	7,632	1,053	12,632
Spencer	9.30	8,273	890	11,630
Stockbridge	3.60	8,238[1]	2,288[1]	9,738
Westborough	4.00	18,689	4,672	.....
Worcester	23.20	125,530	5,411	391,158

[1] Including cost of tank.

TABLE 92.—COST OF MAINTAINING MASSACHUSETTS SAND FILTERS

City or town	Area of filter beds (acres)	Quantity of sewage treated (gallons) per day)	Cost of maintaining filter beds	Cost per acre	Cost per million gallons sewage treated
Andover	3.80	125,000	$638	$168	13.98
Brockton	21.48	878,000	3,538	165	11.04
Clinton	23.50	785,000	2,235	95	7.80
Concord	3.30	312,000	327	99	2.87
Framingham	19.90	652,000	.....	.....	.....
Gardner (Gardner system)	2.67	302,000	1,070	401	9.71
Gardner (Templeton system)	2.25	250,000	849	377	9.30
Leicester	0.36	30,000	125	347	11.42
Marlborough	11.92	1,100,000	1,043	87	2.60
Natick	11.10	566,000	125	11	0.61
Pittsfield	24.78	1,456,000	1,300	52	2.45
Southbridge	7.25	350,000	500	69	3.91
Spencer	9.30	375,000	800	86	5.84
Stockbridge	3.60	75,000	600	167	21.92
Westborough	4.00	282,000	500	125	4.86
Worcester	23.20	2,287,000[1]	.....	.....	6.79[1]

[1] Average for five years, from 1899 to 1903, inclusive.

A study of these and other data indicates that in a general way it costs about $0.20 per capita annually to operate filters of this type on an average.

The investment cost not only varies as is seen above from about $500 (natural beds) to $5000 (artificial beds) per acre, but it is to be borne in mind that there are also necessary long outfall sewers and in some instances pumping stations and force-mains. The figures tabulated above show the total cost in the last column and the details in explanation of these are to be found in the report mentioned.

The cost of land is particularly a variable item in different communities, depending among other things on the amount of land purchased for future extension and to isolate the beds from roads that are frequently traveled.

Sometimes houses are purchased on lands in the neighborhood, although this is not a general custom by any means.

SAND FILTERS FOR FINAL TREATMENT

Coarse grained filters do not give as complete purification as is desired under some circumstances, and to increase the degree of purity of the final effluent the use of sand filters has been proposed. In 1906 the Board of Advisory Engineers at Baltimore recommended final sand filters for the treatment of the sprinkling filter effluent after sedimentation. It was proposed to operate these final sand filters of artificial construction at an average rate of about 750,000 gallons per acre daily. As the influent would normally be non-putrescible and comparatively free from coarse suspended matters, they would be operated more like a continuous water filter than an intermittent sewage filter. Clogging of the sand results from the application of sewage at these comparatively high rates, and at Baltimore it was estimated that it would be necessary to remove on an average about 2.5 cubic yards of sand per million gallons filtered. The cost of removing, cleaning and replacing this sand was estimated at $55,000 per annum for a 100-acre plant, including the care of beds and adjoining grounds.

At the time that the above recommendation at Baltimore was made the sterilization of sewage and sewage effluents was not on a well-established basis. As explained in a subsequent chapter, the cost of sterilization was considered prohibitive, and

it was not until later that the work of Prof. Phelps showed that disinfection or practical sterilization could be accomplished at much reduced figures over that indicated by earlier European data. In consequence of this important step in available methods of freeing filtered sewage from objectionable bacteria, the final sand filters were not built at Baltimore.

Final sand filters have been adopted at a number of plants to provide greater purity than normally afforded either by single or double contact beds. Mr. Clyde Potts has built a sand filter to treat the effluent of a single contact bed at Morristown, N. J. In most plants, however, sand beds have been provided to treat the effluent of double contact beds. With a well-designed and well-operated plant this gives an effluent of excellent character and allows the use of sufficiently large material for the contact beds to guard against serious clogging. A further advantage, as will be explained in the next chapter, is that the contact beds may be filled from below and thus no opportunity is afforded for the sewage to remain upon clogged filter surfaces to putrefy as its passes through the stages of purification up to the point of a stable non-putrescible effluent. Mr. Eddy recommended sand filters to treat the effluent of the sprinkling filters at Gloversville, N. Y.

The first sand filters of this type were installed by the author in 1908 at Togus, Maine, where the winter weather is very severe. A settling basin is provided for the effluent of the second contact beds to pass through on its way to the sand beds. Detached particles from the stone beds putrefy as they lie upon the bottom of the settling basin. Gasification causes these particles to be lifted into the effluent, and this has tended to clog the sand beds somewhat. At the Madison-Chatham plant the author designed a two-story settling tank with a view to guarding the sand filter surfaces against clogging from this source.

If the rate of filtration becomes relatively high in sand filters of this type it is desirable to support the sand layer upon graded gravel as in the case of water filters. For some cases it may be cheaper to reduce the rate and omit the gravel layers.

Indications are at present that sterilization methods will ordinarily prove more satisfactory than high-rate sand filters for the purposes above described. In some instances it may be wise to provide both treatments.

RÉSUMÉ

Intermittent sand filters for about a dozen years, following their first installation at Medfield, Mass., in 1886, were the general method of sewage purification adopted in the United States, other than a few chemical precipitation plants.

In the northeasten section of America, where porous sandy soil is frequently available near cities and towns this method has continued in favor. The results obtained have on the whole proved satisfactory where the filters have been moderately well managed. An average loading for a term of years may be taken as 600 to 700 persons connected with the sewers for each acre of filter surface. The loading depends much upon the character of the filtering material. Loads higher than above given may be used, but they ordinarily mean increased cost of maintenance with scraping as an item of cost sooner or later. It is during the winter that most care must be exercised in the management of this type of filter. If this is not done, it is likely that there will be a serious deterioration in the quality of effluent and perhaps objectionable odors if the clogged filters are not promptly cleaned in the early spring.

With good management the quality of the effluent is the best that can be obtained for a given cost under many conditions. In the southern and western sections of America suitable porous land is not available, and this method, on account of its expense, is unable to compete with high-rate filters of the contact or sprinkling type. Even at Baltimore it was not installed, although sandy soil is available.

Preliminary clarification permits higher rates of filtration than with raw sewage. Various sewages produce clogging in different ways, so that it is scarcely feasible to state filter loadings more definitely than to indicate that rates about double that which can be used for raw sewage are as favorable as can be now forecasted for clarified sewage.

Sand filters have had a limited field of usefulness for the final treatment of the settled effluents of coarse-grained filters, but for this purpose thev are being superseded in new installations by sterilization methods.

CHAPTER XX

CONTACT FILTERS

This method of treatment consists of applying sewage to filters of fairly coarse material until the pores of the broken stone, coke or slag of which the filters are composed are filled, then of allowing the filter to stand for a short period with its pores filled, and finally in draining the sewage from the filters. By this procedure, which may be repeated two or perhaps three times per day, nitrification is brought about and there is obtained an effluent which is fairly stable as to its residual organic matter. Under favorable conditions this type of filter will produce an effluent which does not putrefy, although greatly inferior ordinarily to the effluent of intermittent sand filters as regards appearance, turbidity, organic matter and bacterial content. The contact filter has its field of usefulness in connection with the elimination of nuisances associated with decomposition odors, rather than the removal of disease germs. In the latter respect, however, it may be of use in connection with other styles of treatment.

NOMENCLATURE

Contact filters are sometimes spoken of as contact beds, oxidizing beds, bacterial beds or biological filters. Filters and beds are practically interchangeable expressions and there is no misunderstanding in regard to them. As practically all sewage filters are in a certain sense bacterial or biological devices, it is believed that it is best to avoid the use of this expression for this or any other particular kind of filter. While these devices are not filters in the sense of being complete strainers for the mechanical detention of all the applied suspended matters, still with certain limitations they are filters in that the matters to be removed, particularly the organic matters, are retained in contact with the surface of the particles of filtering material for such time and in such manner as will promote oxidation and biological activities in the presence of oxygen. After reading the descriptions in the preceding chapter on the early work at Lawrence with sand filters, it will be appreciated

that careful attention should be given to the filtration aspect of these devices which we prefer to call contact filters or contact beds.

HISTORICAL DEVELOPMENT

English Origin.—Coarse-grained filters operated on the fill-and-draw plan were first studied by the London County Council in 1892 at the Barking outfall of the London sewerage works under the direction of Sir Alexander Binnie, Chief Engineer, the late Mr. Santo Crimp, District Engineer, and particularly Mr. W. J. Dibden, at that time Chief Chemist. They were the outcome of the gravel filters studied at the Lawrence experiment station of the Massachusetts State Board of Health. Their purpose was to provide purification at a higher rate and at less cost than was feasible with intermittent sand filters, particularly in places like London where porous sandy material in place is not available. As a result of classic reports by Mr. Dibden on the early tests at Barking, a filter one acre in area consisting of 3 feet in depth of coke breeze was put in service at that place in September, 1893. During the next year contact beds were studied by him at Sutton in Surrey, England, where the feature of "double contact" was first undertaken. In England they have been installed at many places, the largest plant being at Manchester.

Adoption Slow in America.—Experimentally contact filters were studied in this country at Lawrence beginning in 1894. But they did not meet with much favor for municipal installations prior to 1900, although their use at Columbus, Ohio, was advised in 1898 by Messrs. Griggs and Alvord. Shortly thereafter they were recommended at Plainfield, N. J., by Messrs. Osgood and Gavett and at Mansfield, Ohio, by Messrs. Snow and Barbour. The former plant was on the double contact basis with an aggregate area of about 1.8 acres, as described in *Engineering News* of Jan. 12, 1901, page 30; also in the *Journal of the Association of Engineering Societies*, May, 1904, page 263. The Mansfield filters provide single contact with about 1.25 acres, as described in the Annual Report of the Ohio State Board of Health for 1900, page 138.

Disadvantages.—Shortly after this the tests at Columbus, Ohio, and the Massachusetts Institute of Technology in Boston showed in confirmation of the Lawrence studies that sprinkling filters as described in the next chapter are so much more econom-

ical that contact filters have rather fallen into the background since that time, so far as large undertakings are concerned. It is significant that comparatively little or no attention was paid to contact filters, as distinguished from sprinkling filters, at the testing stations conducted at Waterbury, Conn.; Baltimore, Md.; Gloversville, N. Y.; Philadelphia, Pa.; and Chicago, Ill.

Advantages.—Contact filters, however, have certain distinct fields of usefulness. This is partly on account of the smaller head which they require for their operation as compared with sprinkling filters, thus allowing in some instances a gravity flow through the plant, where pumping would be required for sprinkling filters. Their standing is also partly accounted for in small installations by the desire to avoid the odors incident to filters of the sprinkling type. This feature causes them to be viewed with less prejudice by neighboring property-holders than sprinkling filters. This is particularly true where double contact filters are filled from below to within some 4 to 6 inches from the surface, thus preventing (in a suitably designed plant) the sewage from being exposed to view until it has reached an odorless state.

While contact filters have made no headway recently for large installations, they have been adopted for quite a number of towns and small cities where it is difficult or expensive to obtain isolated sites for disposal works. Within the past few years the author has recommended their use for six or eight projects. In New Jersey alone there are now a dozen or more filters of this type, most of which have been recently built.

For very small plants contact beds have an advantage over sprinkling filters in that they can handle readily the relatively high rates of flow which come from small groups of residences, institutions, etc.

Coarser filtering material has been recently used than was formerly the case and this has had an influence in restoring contact filters to somewhat greater favor than was the case a few years ago, through minimizing of the cost of cleaning the filter media. For that reason engineers hesitated in recommending them.

EFFICIENCY

In 1904 practically the only American data of importance as to the efficiency of contact filters were those obtained at the Lawrence experiment station, from which the author compiled averages as shown by Table 93.

TABLE 93.—SUMMARY SHOWING AVERAGE LAWRENCE DATA IN 1903 REGARDING RATE OF FILTRATION AND EFFICIENCY OF CONTACT FILTERS

Filter number	Filtering material: Kind	Filtering material: Depth in inches	Filtering material: Size	Years covered by averages	Preparatory treatment received by influent	Average number of gallons applied per acre daily for 7 days in the week	Influent: Parts per million: Oxygen consumed	Influent: Parts per million: Nitrogen as Ammonia: Alb.	Influent: Parts per million: Nitrogen as Ammonia: Free	Influent: Parts per million: Chlorine	Influent: Bacteria, per cubic centimeter	Effluent: Parts per million: Oxygen consumed	Effluent: Parts per million: Nitrogen as Ammonia: Alb.	Effluent: Parts per million: Nitrogen as Ammonia: Free	Effluent: Parts per million: Nitrogen as Nitrates	Effluent: Bacteria, per cubic centimeter
81	Ashes and cinders.	54	?	1897–Oct. 1, 1898.	Strained through coke.	647,000	20.9	3.33	28.4	79.1	1,534,000	12.1	1.62	15.4	10.8	407,000
103	Coke	60	1/8 to 1/4 in.	Mch. 1, 1898–1902.	Septic tank	595,500	27.3	3.29	38.7	97.4	760,400	7.8	0.87	7.9	21.2	94,900
107	Cinders	24	Free from ashes.	1898–Oct. 1, 1899.	None	553,000	34.5	4.59	23.8	67.8	1,840,000	15.7	1.68	13.4	5.4	445,000
108	Coke	24	Free from dust.	1898–June 1, 1900	Contact to 1900, then coke strainer.	441,000	18.0	1.99	17.7	73.7	540,000	9.5	1.00	5.8	11.9	230,000
108*a*	Coke	48	Same as No. 108.	Aug.–Dec., 1900	Strained through coke.	466,200	27.9	3.22	32.0	99.0	1,010,600	11.2	1.34	9.8	19.5	630,000
117	Broken stone.	126	1/2 to 2 in.	May–Dec., 1899	None	1,626,000	42.5	5.19	30.2	77.2	2,084,000	10.9	0.79	6.0	18.8	144,000
135	Broken stone.	214	1/4 to 1 in.	May–Dec., 1900	None	1,206,000	49.5	5.56	37.8	102.6	2,947,000	13.3	1.74	20.3	3.4	438,600
137	Broken stone.	?	1/2 to 1 in.	1900–1902	None	663,180	42.6	5.88	36.3	96.7	2,623,700	21.1	2.59	22.3	8.3	563,200
154	Coke breeze	48	?	Sept.–Dec., 1900	Septic tank	487,020	45.4	6.59	58.7	116.7	2,234,000	14.9	2.22	42.3	3.0	356,700
163	Coke	54	Fine	1901–July 1, 1902	Contact No. 137.	609,000	21.2	2.36	24.3	97.8	429,000	10.3	1.36	12.0	14.6	336,000
164	Coke	54	Considerably finer than No. 163.	Jan.–June, 1901	Contact No. 137.	655,560	20.4	2.40	24.2	101.4	383,800	9.4	1.15	8.6	21.7	210,300
167	Broken stone.	48	Walnut.	Mch.–Dec., 1901	Septic tank	340,000	65.9	8.50	85.3	117.7	321,700	20.9	3.24	54.6	13.4	227,000
175	Coke	60	1/4 to 1 in.	1901	Strained through coal.	779,820	25.2	3.63	36.1	116.1	760,000	10.5	1.42	13.5	13.4	131,500
176	Coke	60	1/4 to 1 in.	1901–1902	None.	663,500	42.8	6.06	37.2	100.7	2,568,000	7.7	1.52	13.1	11.3	413,200

The next important line of evidence was that obtained at the Columbus sewage testing station. As stated in Mr. Johnson's report, tests were made with four primary and two secondary contact filters. All of the filters were 5 feet in depth above 6 inches of underdrains. The material was freed from particles which would pass through a screen with 0.25-inch mesh, and was composed of particles which would be retained on a screen with a mesh of about 1.5 inches. There were some variations in this range in the case of some of the filters. The conclusion from the Columbus experiments was that with filters 5 feet in depth a non-putrescible effluent could not be obtained at an average rate or yield of one million gallons per acre daily. A safe average daily rate was stated to be in the neighborhood of 600,000 to 700,000 gallons per acre.

Profs. Winslow and Phelps, on page 148 of Water Supply and Irrigation Paper No. 185, summarized their conclusions as to important tests with contact beds at the experiment station of the Massachusetts Institute of Technology. With single contact beds of 0.5-inch stone operated at a rate of about 1.2 million gallons, it is stated that the effluent was generally so stable that it could be discharged into a considerable body of water without creating any nuisance. The difficulty with this bed was that it clogged rapidly. A better combination was found to be with beds 6 feet deep with the primary bed composed of 2-inch material and the secondary bed of 0.5-inch material. This system of double filtration clogged much less seriously than the single contact bed and gave a fairly well purified and stable effluent at an average rate of about 700,000 gallons per acre daily.

While different sewages receiving different preparatory treatments and filters of different depth and different size of material naturally show considerable individuality, yet the evidence above stated shows that there was quite close agreement at Lawrence, Boston and Columbus as to feasible rates and the efficiency to be obtained from filters of this type.

Plainfield Data.—The contact filters at Plainfield, N. J., are the only ones with which the author is familiar that have been tested carefully in actual practice with a resident chemist in charge. This plant comprises 8 primary and 8 secondary beds, all of the same area, which aggregates a little less than 3.6 acres. One-half of this plant was built in 1901 and the other half in 1905.

The primary beds were originally filled with material about 0.25 to 1.00 inch in size to a depth of 4.5 feet over 6 inches of underdrains. These beds became seriously clogged in about four years and all of the material was taken out, washed and replaced in 1905. The material in the primary beds built in 1905 ranged from about 0.5 to 1.0 inch. The author has been connected with the operation and improvements to this plant from time to time since the latter date, and has given much study to the clogging of the beds. Since 1910 the plant has been seriously

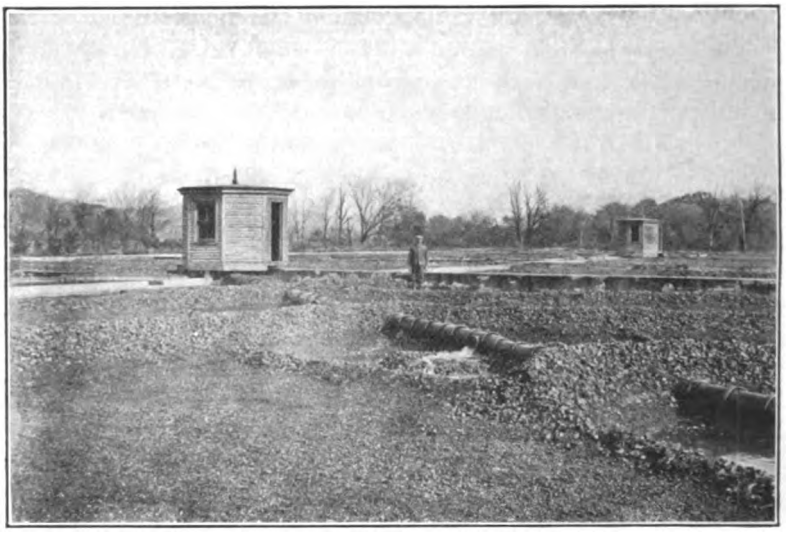


FIG. 62.—Contact beds, Plainfield, N. J.

overworked, due to the clogged condition in which it was allowed to remain and to the increasing volume of sewage which it was obliged to treat. The present plant is described by Mr. Gavett in *Engineering News* of May 5, 1910; also by Mr. Lanphear in the *Engineering Record* of July 1, 1911, and Jan. 13, 1912.

The composition of the influent of the Plainfield beds is given on page 471. A view of these works is shown in Fig. 62, through the courtesy of Mr. Andrew J. Gavett, City Surveyor. As already stated, the sewage (about 100 gallons per capita daily) is passed through single-story septic tanks holding about nine hours' flow. Gas-lifted sludge particles are a serious factor with respect to clogging of the comparatively fine-grained contact

beds. In the autumn of 1910 trenches about 4 feet wide were dug through the full depth of the primary beds and trap rock of an average size of about 1.5 inches was placed in these trenches to facilitate the distribution of the sewage to and the withdrawal of the effluent from the primary beds. This expedient worked reasonably well for a time, but beginning in the summer of 1911 the results have been unsatisfactory from time to time, particularly during the colder season of the year. The original secondary beds were filled with 0.12- to 0.75-inch material and the 1905 beds with 0.5- to 1.0-inch material, although there are some variations from these sizes.

The following table shows the monthly averages of daily results as summarized by Mr. Lanphear in an article in the *Engineering Record* of July 1, 1911:

Dissolved oxygen was rarely present either in the influent or the effluent of the primary beds. In the effluent of the secondary beds, however, the dissolved oxygen usually averages between 2.5 and 4 parts per million.

The putrescibility tests were made by the methylene blue method with incubation at room temperature for 10 days and by the test for residual dissolved oxygen in a sample kept in a closed bottle at room temperature for 48 hours. The latter test has been the one usually employed at Plainfield. Mr. Lanphear in the article above mentioned describes special comparative tests with 22 samples of undiluted primary contact effluent which showed no dissolved oxygen present at the end of 48 hours. The blue color disappeared from all the 22 samples in less than one day. Twenty of the samples of the primary contact effluent, diluted one to one with tap water, were putrescible, and the other two were non-putrescible, according to the 48-hour test with dissolved oxygen. The blue color disappeared from the 20 samples in about two days, and from the remaining two in about four days.

All the samples of undiluted secondary contact effluent were non-putrescible according to the 48-hour test with dissolved oxygen. Sixteen of the samples with methylene blue retained their color for 10 days. The blue color disappeared from the other 6 samples in from 5 to 11 days. All samples of the secondary contact effluent diluted one to one were non-putrescible according to both tests.

The 48-hour room temperature test with dissolved oxygen

TABLE 94.—MONTHLY SUMMARY OF RESULTS, PLAINFIELD SEWAGE DISPOSAL WORKS, 1910

1910	Weir reading million gallons	Parts per million: Suspended matter				Parts per million: Oxygen consumed				Parts per million: Nitrogen as nitrates		Parts per million: Nitrogen as nitrites		Putrescibility		Bacteria: Millions per cubic centimeter				Per cent removed	
		Screened sewage	Septic effluent	Primary effluent	Secondary effluent	Screened sewage	Septic effluent	Primary effluent	Secondary effluent	Primary effluent	Secondary effluent	Primary effluent	Secondary effluent	Primary effluent	Secondary effluent	Screened sewage	Septic effluent	Primary effluent	Secondary effluent	Filters alone	Entire system
Jan.	1.9	116	50	18	7	74	56	27	10	0.9	3.5	0.16	0.08	* *	° °	.....	.....	.....	.....	.....	.....
Feb.	1.85	114	50	20	12	74	53	25	14	0.9	2.3	0.12	0.04	* *	° °	1.27	0.95	0.51	0.19	80	85
Mar.	1.7	133	58	19	9	78	56	26	11	0.4	2.9	0.13	0.08	* *	° °	2.04	2.44	1.09	0.52	79	74
Apr	1.7	138	45	24	12	71	50	27	12	0.5	4.4	0.10	0.20	* *	° °	2.27	1.43	0.79	0.38	73	83
May	1.65	168	42	19	7	74	52	27	11	0.2	3.1	0.03	0.17	* *	° °	2.66	1.44	0.82	0.47	67	81
June	1.7	156	47	32	10	72	51	34	12	0.1	2.9	0.01	0.26	* *	*° °	2.87	1.40	0.77	0.44	69	81
July	1.7	142	65	32	16	62	49	29	12	0.1	2.2	0.01	0.27	* *	* °	2.67	1.26	0.78	0.44	65	83
Aug.	1.65	146	55	25	7	60	46	26	8	0.3	3.1	0.01	0.16	* *	*° °	2.96	1.69	1.09	0.71	59	76
Sept	1.7	152	55	38	12	72	50	29	9	0.2	2.9	0.01	0.15	* *	*° °	2.59	1.43	0.81	0.46	68	82
Oct:	1.5	196	60	31	11	86	55	31	11	0.3	3.4	0.04	0.14	* *	° °	2.22	1.09	0.56	0.33	70	85
Nov.	1.6	271	69	32	11	100	60	29	10	0.8	4.4	0.14	0.15	* *	° °	2.37	1.57	0.97	0.51	67	78
Dec.	1.9	191	72	29	10	92	60	29	10	0.5	4.2	0.07	0.09	* *	° °	2.09	12.5	0.66	0.28	78	87
Av.	1.7	152	56	27	10	76	52	28	11	0.4	3.3	0.07	0.15	* *	° °	2.36	1.45	0.80	0.43	70	82

Note.—* = Putrescible. ° = Non-putrescible. Figures at left of putrescibility column, undiluted; figures at right diluted, 1:1.

appeared to be sufficiently accurate if the samples are definitely putrescible or non-putrescible. If the putrescibility is questionable the dissolved oxygen test has a tendency to give non-putrescible results, when the blue color in the methylene blue test remains only from 4 to 10 days. The experiment also indicated that in such cases the blue color remained at least four days.

The bacterial removal by the Plainfield filters varies somewhat, but on account of the fineness of the filtering material it is probably somewhat greater than could be reasonably expected of the more modern beds of coarser material and of a depth within the ordinary limits of 4 to 6 feet.

There is considerable variation in the quality of the effluent of contact filters, depending upon the rate at which the effluent is drawn from the bed and upon other factors. The first portion of the effluent if removed at a high rate is apt to be distinctly inferior in quality to that of a fair average sample. Conversely the effluent last drained from the beds at a slow rate is likely to be better than the average. At Plainfield much care has been taken to have the samples represent average conditions.

Messrs. Clark and Gage in recent Reports of the Massachusetts State Board of Health give many interesting details of the experimental contact filters at Lawrence and Andover, particularly in the Report for 1908, page 424. Their main evidence is practically in harmony with the above general outline of the efficiency of this type of filter.

In summary it may be said that the removal of applied organic matter varies much, due to the influence of local factors, but ordinarily it is from 60 to 80 per cent.

Where filters of coarse material are used it is found that, while the effluent as a whole is non-putrescible or stable, the solids in the effluent will decompose and gasify when allowed to remain separated from their pro rata share of liquid.

CAPACITY

General evidence now available in America shows that contact beds will give a non-putrescible effluent when on an average they treat from 125,000 to 150,000 gallons per acre daily for each foot in depth of effective filtering material. When free of clogging the beds may for a time work at rates appreciably higher than this, and with coarse material it may be that filters may be

permanently operated somewhat in excess of the above rates. Recently it has been the custom of the author to assume an average rate of 600,000 gallons per acre daily for contact beds of an effective depth of 4 to 5 feet. Within certain limits the capacity is proportional to the depth. For short periods contact filters may be satisfactorily operated at rates much in excess of the average daily yield.

It is significant that with weak American sewages the rate of filtration seldom exceeds that secured with strong European sewages. With coarse material this may not hold true.

RELATION TO PRELIMINARY AND FINAL TREATMENT

With filters as fine as in use at Plainfield clogging is a factor of such importance as to make it advisable to clarify sewage by some preliminary treatment so far as this is economically feasible. This is desirable with materials of coarser size, but apparently it is not so important as with fine material, because there is less likelihood of the solid matters interfering with the proper aeration of the voids of the filtering material.

While filters of fine material give trouble as to clogging, they produce a fairly clear effluent. In fact, the effluent of the Plainfield beds with about 10 parts per million of suspended matter is not likely to give trouble. If the materials in both primary and secondary beds, however, are coarse, there is an unloading of deposits from the filtering material and the effluent is ordinarily of quite an unsatisfactory appearance on account of suspended matters. The latter may be removed in settling basins holding about one to two hour's average flow. Two-story tanks have been designed by the author for this purpose in order to prevent gasification of the solids from interfering with the quality of effluent. In another case a Dortmund tank was designed with the view of separating the solids from the effluent of the filter and delivering them to the primary two-story septicization tanks.

If need be the final effluent may be applied to sand filters, as in the case of the plant at Chatham, N. J., described in the *Engineering Record* of Jan. 27, 1912.

In a report on the extension of the Plainfield beds in 1911, the author advised the use of new coarse material for primary beds, and an intermediate sedimentation basin, the effluent of which would be applied to secondary filters of fine filtering

material obtained from washing the stone and slag in the existing filters.

It is thus seen that sedimentation is a feature to be considered in connection with contact filters. Under varying local conditions it may be applied as a preliminary treatment or as a final treatment or an intermediate treatment in cases where there are double contact beds.

PRINCIPLES OF PROCESS

This question has been touched upon in general terms in connection with the Hampton doctrine in Chapter XVII. The process which takes place in contact filters is more complicated than in intermittent sand filters. If the period of contact is too long, oxygen is exhausted within the filter and anaerobic decomposition sets in. The efficiency depends upon the retention of finely divided organic matters, particularly of a colloidal nature, under such conditions that they do not appear in the effluent until their putrescibility is materially reduced; and in maintaining the surfaces of the filtering particles in such shape that the enzymes and other biochemical developments are allowed to proceed advantageously.

The physical aspects of the case are highly important and involve means, as indicated in the Hampton doctrine in Chapter XVII, of retaining as much fine suspended matter within the filter as is feasible without serious complications from clogging. The filtering material requires frequent aeration in order that absorption may bring about rapidly the important purification described by Drs. Dunbar and Thumm in the Hamburg tests in 1902, and other articles from that important testing station. The absorption deals with direct oxidation of the organic matter in the sewage, as it flows over the films, partly by ferments or enzymes and partly by oxygen in an active state within the pores of these films. An excellent description of this phase of the process is given by Dr. Dunbar in his book on the "Principles of Sewage Treatment."

Biologically the contact filter is not simply a mechanism in which the bacteria feed upon stored organic matter and gradually convert it to nitrates. Such bacterial activities no doubt abound when a bed is drained and when oxygen is present while the bed is full or partially filled. At intervals the biochemical activites need regeneration, and this seems to be effected by biological

action upon the films in the presence of oxygen. If oxygen either from the atmosphere or from nitrates within the filter is not present, the bacteria proceed quickly upon an anaerobic basis and this may develop serious complications.

The process has then for its underlying principles the maintenance of biochemical and biological activities on an oxidizing basis upon and within the films surrounding the filtering material; and at the same time the providing of physical conditions so that the non-settling and colloidal organic matters are reduced in putrescibility by oxidation either by absorption action of these films or by biological action.

CHARACTER OF FILTERING MATERIAL

Mechanical Analysis.—It has usually been the custom for engineers to speak of filtering material as having been screened between certain limits, such as between 0.5 and 2 inches. In some localities the stone is spoken of as 1-inch or 1.5-inch material, according to the custom of local quarrymen. In some instances, a good deal of difference of opinion as to material has arisen from lack of precision with respect to this feature. A convenient and concise way of stating the size of the material as an average is to give the diameter of a sphere having a volume equal to the average volume of a carefully selected representative portion of the material. The specific gravity of the material being known, it is a simple matter to compute this by noting the average weight of 50 to 100 carefully selected pieces of the material from different places. An approximate statement as to the relative lengths of the maximum, minimum and mean axes of the particles is also instructive. The range in grading of sizes, when carefully studied, frequently gives results which are quite surprising to those who make simply a casual observation of filtering material in place. It could be recorded quite readily by computing, as indicated, the diameter of a sphere having a volume equal to the average volume of the largest 10 per cent. and the smallest 10 per cent. of the pieces, respectively.

Percentage of Voids.—The interstices within the filtering material have much influence upon the quantity of sewage which may be treated. The grade of stone or slag exercises much influence upon the percentage of voids which for new material usually ranges from about 40 to 50 per cent. The higher the percentage of voids without increasing the cost of filtering

material, the better it is for this purpose. Almost all of the early contact filters were of such fine material that more or less clogging ensued with a gradual diminution of voids until it became necessary to remove the material and clean it. Obviously a contact bed with 20 per cent. of voids will have a far less capacity than one with 40 per cent. of voids. More than this, the amount of sewage held by capillarity within the filter usually interferes with the proper entrance of air, and the oxidation of organic matter is less in amount for a clogged bed than would be indicated by a comparison of the percentages above given.

Kind of Material.—Material with rough surfaces, such as slag, is more efficient for a time at least than is stone with its ordinarily smooth surfaces. The importance of this is marked on account of the influence which it exerts in the removal of non-settling or colloidal matters. Gradually films are formed around the particles and the effect of the kind of material largely disappears.

It is particularly important to use material that is durable and which will not disintegrate and thus lessen the voids in this way. While stone is somewhat less efficient than slag, it is a perfectly satisfactory medium for filters of this type.

Size of Material.—The early Lawrence work pointed to a material of about 0.5 inch in average size screened between 0.25 and 1.0 inch as best adapted to the use of contact filters. It was thought at that time that the loss in capacity of the voids might be counteracted by allowing the filters to rest so that the films around the particles of stone could in part crack, peel and pass from the filter with the effluent. This has not been found to be satisfactory at Plainfield for the primary filters, but the size above is reasonable for the secondary beds. For the primary beds at the new project at Plainfield, it was recommended that the material be screened between 1.0 and 2.0 inches, or such as is spoken of locally as 1.5-inch material. The material had best be of one grade. Fine material above coarse promotes clogging.

Underdrainage.—Experience on a large scale has shown that it is wise to provide more liberal underdrainage than was the case with the early filters. With fine filters this is not so important as in the case where larger material has been used. If the material is coarse enough to unload the particles which form films around the stone, these particles pass to the floor and are inclined to stay there unless conditions are favorable for their

removal. Even with material as fine as that in the Plainfield beds, it is the inability of the underdrains to remove suspended particles which has had much to do with the clogging and necessity for cleaning. False bottoms for contact beds containing coarse material are distinctly helpful and are probably worth more than their cost through the saving which they effect in cleaning the material.

Depth of Material.—A majority of contact beds are built of a depth from 4 to 6 feet and perhaps 5 feet might be considered average practice. Where the material is fine, depths less than this are feasible, and are sometimes used in order to save the expense of pumping. Where filters are provided with a false bottom, there is a tendency to make the beds deeper than in earlier practice rather than shallower.

FEATURES OF CONSTRUCTION

Filter Walls and Floors.—These should be built water tight. Concrete is used almost exclusively for this purpose in this country. The floors have a slope of about 1 to 100 and a greater slope than this is rather desirable. A few attempts have been made to place filtering material upon earth bottoms, but it is not considered a wise practice for any ordinary conditions.

False Bottoms.—Beginning in 1907 the author has recommended in all cases the use of a false bottom ordinarily built with half-round tile as for sprinkling filters. Over these false bottoms is placed coarse stone which in turn supports the filtering material. The effluent passes through the joints in the half-round pipe to the floor beneath where velocities are ordinarily maintained which prevent objectionable deposits of suspended matter. Without a false bottom, deposits of a black and slimy appearance accumulate, interfere with draining and the entrance of air to the bottom of the bed, and in these ways reduce the capacity of the filter and increase the cost for its maintenance.

Single vs. Double Contact.—On the whole the evidence indicates that double contact is rather more efficient than single contact when the rate is expressed in volumes of sewage treated per cubic yard of filtering material. There are probably exceptions to this rule, and particularly so if contact filters are to be operated in conjunction with other devices. Thus, at Morristown, N. J., Mr. Clyde Potts has built a single contact filter, the effluent of which is applied to intermittent sand filters of arti-

ficial construction. Single contact beds per unit volume of material are cheaper to build on account of the saving in floor, walls and false bottom. Topographical conditions sometimes are of much importance in the consideration of this factor.

Number of Units.—There should be at least three units of filters and for large plants the number may be increased to advantage.

FEATURES OF OPERATION

Rate of Filling.—Within the author's observation it makes practically no difference at what rate sewage is allowed to enter contact filters in normal operation. Generally speaking, the quicker the better.

Contact Period.—It was the custom in earlier years to make the period of contact several hours. This has a tendency to accentuate the anaerobic decomposition of the contents of the filter and it is considered preferable by the author to begin to drain the bed ordinarily in about 15 to 30 minutes after it has been filled. Illustrative of the disadvantages of anaerobic conditions, mention may be made of the behavior of some contact beds when first built and when the amount of sewage reaching them is far below the normal. Under such circumstances the beds should only be partially filled, because if by chance the sewage is allowed to flow into and remain within the filter for a day or two, so-called septic conditions may be established to a highly objectionable degree.

Rate of Draining.—As it is the belief of the author that organic matter is oxidized best when the films of the filtering material are supplied for the greatest percentage of the time with atmospheric oxygen, it naturally follows that the period of rest should be as great as practicable. This means that draining should be accomplished as rapidly as is consistent with a reasonable detention of suspended matters within the filter. If the draining is too rapid, there is liable to be (with coarse filtering material) a washing out of suspended matter that does not make for a high quality of effluent. On the other hand, with fine material it is difficult to wash out much of the clogging matters by rapid draining. The best way is not to allow the material to become seriously clogged.

Filling from Below.—In 1906 the author was much impressed with the custom in vogue then at Langensalza, Germany, and

Hampton, England, of filling contact filters from below. All contact filters designed in the office of the author since that time have been on the basis of providing filters with a false bottom, applying the sewage from below to within about 6 inches of the top and proceeding otherwise as with the ordinary top-filled beds. There seems to be no disadvantage to this arrangement so far as removal of organic matter is concerned, and there is the great advantage of preventing the unfiltered sewage from being exposed to view until it has reached a non-putrescible stage. This arrangement naturally calls for double contact beds. Clogging is much less likely to occur than with top-filled beds, but where coarse filtering material is so used, the effluent should be settled before its discharge either to sand beds or to a water course, unless the latter is muddy and comparatively large. At Plainfield the primary beds have been filled from below since 1910, but the fine secondary beds have always been filled from the top.

Ripening.—Contact beds do not give normal results when they are new. It takes several weeks for the needed films to become formed in a good working condition upon the surfaces of the filtering material. The required period varies with the size of the material, the season of the year and the manner of operation. Fine material becomes ripened more quickly than coarse material, other things being equal, and with equal depth gives a rather better effluent. This is partly due to the area of films upon and within which biochemical actions take place. In part it is due to more suitable conditions for the retention of undissolved matters. Very rapid draining tends to retard the formation of these films.

PERMANENCY—CLOGGING

Fine Material.—Contact filters of fine material, say of an average diameter of about 0.5 inch or less, have several distinct advantages over coarser material. They are better clarifiers, and in proportion to their depth will give somewhat better purification owing to the greater area of films around the particles of filtering material. Consequently there is more opportunity for biochemical and biological actions. But they show disadvantages due to clogging. In part this shows itself at the surface, but it also affects the main body of material and the underdrains at the bottom, so as to interfere with prompt and complete draining.

Plainfield experience shows that when the primary beds are filled from the top there is a scum of fairly dry suspended matter to be raked from the surface. It amounted in 1909–10 to about 0.5 cubic yard per million gallons. Furthermore, the voids in the main body of material become gradually reduced so that in 4 to 5 years they are only about one-half of the original interstices. The capacity of the beds is then so reduced that it is best to remove and clean the material. This costs about $0.60 per cubic yard, under the conditions at Plainfield.

Coarse Material.—When the average size of the material is from 1.0 to 1.5 inches in diameter, the present indications are that with good management it is unnecessary to remove and clean the material on account of clogging. This permanency of construction is obtained at a considerable cost, in that it involves the use of false bottoms, final or intermediate settling basins for treating the decomposable solids in the effluent, and perhaps a greater quantity (depth) of material to afford equal treatment of the sewage, as compared with beds of fine material. The influence of the rate of filtration with beds of fine and coarse material depends upon local conditions.

As well stated by Dr. Dunbar, it is a financial proposition to determine which is preferable for a given problem:—Fine material with its expense to remove clogging, or coarse material with less expensive maintenance but greater first cost for installation.

TEMPERATURE CONDITIONS

So far as known winter conditions have not seriously interfered with the operations of well-managed contact filters. If top-fed filters were allowed to become seriously clogged at the surface, it is natural to expect that the applied sewage might freeze at times of severely cold weather.

With bottom-fed filters no complications are said to have been experienced at Togus, Maine, where such a plant has been in service since 1908 in a climate with heavy snows and much zero weather.

Oxidation processes are normally reduced somewhat in winter, as compared with summer results, particularly as to nitrification and other products of bacterial activities. It is not unusual with contact filters to find the nitrates in the effluent rather higher in winter than in summer. Here the greater bacterial activites in summer no doubt produced more nitrification, but the nitrates

were reduced more in summer than in winter by certain types of bacteria in the effort to continue on an aerobic basis at times when insufficient atmospheric oxygen reaches the lower portions of these clogged filters.

HIGHER FORMS OF LIFE

Worms and flies have not been conspicuous at any of the American contact filter plants that have come to our attention. Messrs. Clark and Gage in their 1908 summary, page 409, refer to the presence in one instance at Lawrence of a large number of worms of a form similar to ordinary earth worms. They made their home in the filtering material of one filter for several years, practically covering the surface when the filter was filled with sewage and returning below when it was drained. It is stated that they must have played a considerable part in conjunction with other small organisms (excluding the bacteria) in working over the organic matter stored in the filter.

Flies have rarely if ever been conspicuous around American contact filters.

AUTOMATIC DOSING DEVICES

The question of application of sewage to contact filters, as to whether it is fed to the surface of the filter or from below, has already been discussed. The method of rotating the sewage from filter to filter requires considerable study, depending on local conditions. The author is strongly in favor of using some style of the several admirable arrangements available in America for controlling automatically the operation of contact beds. At Plainfield, N. J., it is recommended that this be done in the interests both of efficiency and economy. For an investment of about $5000 a plant of a capacity of three million gallons daily may obviate the expense of a night attendant. This applies of course to filters of moderately coarse material where it is unnecessary to remove scum and deposits associated with clogging and where advantageous use is taken of preliminary and intermediate settling basins.

The devices best known in this country are the airlock devices manufactured by Merritt and Co. and the Pacific Flush Tank Co.; the moving-part devices manufactured by the Cameron Septic Tank Co. and the Ansonia Manufacturing Co.; and the Barbour apparatus, which is a combination of an airlock

siphon and mechanical device. The device designed by Mr. Barbour and made by the East Boston Iron Works, for contact filters, is similar to his apparatus for operating sand filters, as previously described and as shown on Fig. 60, page 660. The device manufactured by the Ansonia Manufacturing Co. is shown on Fig. 56, page 657. This device consists of a rocker arm to which are attached a set of operating buckets and of plug valves

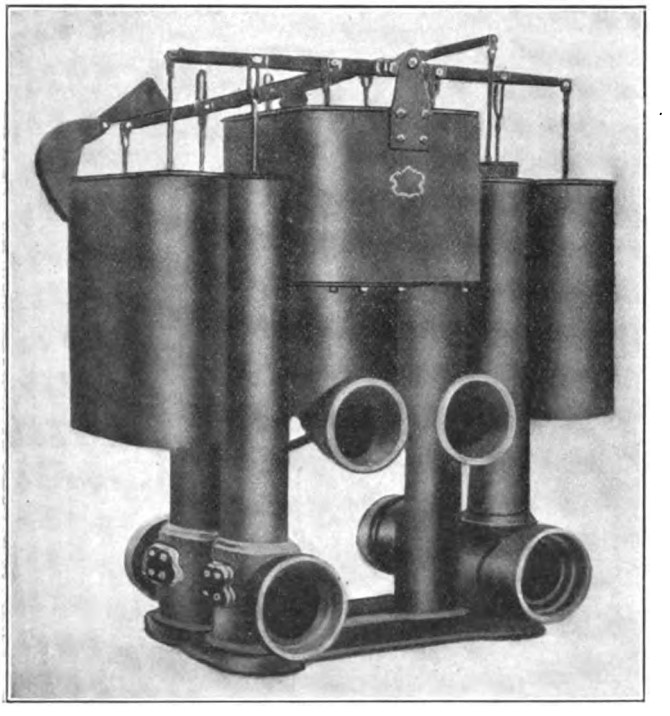


FIG. 63.—Dosing device of Cameron Septic Tank Co.

leading to the different filters. The filling of one contact filter fills the bucket connected to this filter and by its weight when full of sewage lowers the rocker arm, closes the inlet valve to that particular filter just filled and opens the valve to the next one. Fig. 63 shows a dosing device manufactured by the Cameron Septic Tank Co. for the control of the application of sewage to contact filters. The rise of the sewage in the four outside chambers actuates floats which in rising close the inlet valve to the filter in use, open the outlet valve to the filter

previously filled, and open the inlet valve to the next succeeding filter. Fig. 64 shows a device similar to that installed by the Pacific Flush Tank Co. at Togus, Maine; Bordentown, N. J., etc. This apparatus is without moving parts and is actuated entirely by air compressed in the air domes by the rising sewage in the control chambers. In the inlet chamber the air compressed under the large air dome is forced into the "feed" then operating, stopping the flow. The compression of air under the small dome releases the blow-off trap of the feed next to be used. Any number of beds may be put out of service and the rest used in rotation by simply changing the three-way cocks on the air

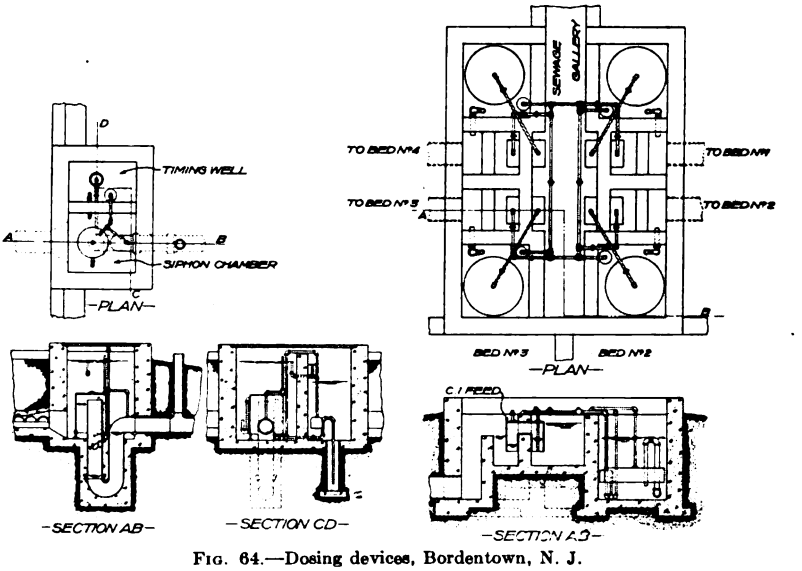


FIG. 64.—Dosing devices, Bordentown, N. J.

piping. The outlets are controlled by time siphons which allow a regulation of the time of contact. Fig. 65 shows a device installed by the Merritt Manufacturing Co. on the Ridgewood, N. J., contact filters. This, like the Pacific Flush Tank Co.'s device, has no moving parts. The opening and closing of the sluiceways is effected by means of a flush of air accumulated in a casting placed in the filter bed, with which the inlet is connected and in which the air is compressed sufficiently to eject the water seal and permit the passage of the compressed air to the inlet sluiceway of the filter bed in use and thus closing it. This

same movement also opens the inlet to the bed next to be used and opens the outlet siphon to the previously filled filter bed.

ODORS

Contact filters have given no trouble as regards odors where the maintenance has been attended to conscientiously. The same cannot be said, however, of filters filled from above which are neglected so that accumulations of scum remain for some time upon the surface. Such filters give an odor sometimes noticeable for some little distance away.

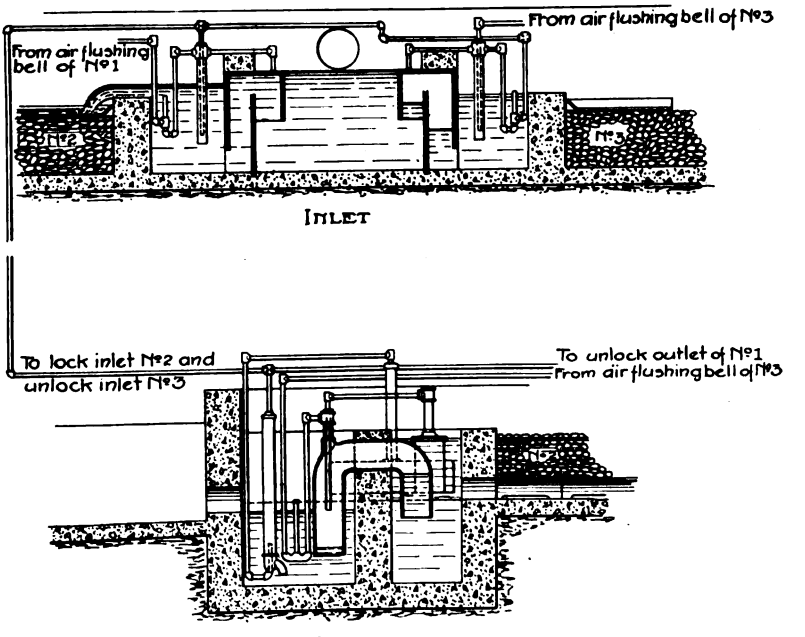

From air flushing bell of N°3
From air flushing bell of N°1
N°2
N°3
INLET
To lock inlet N°2 and unlock inlet N°3
To unlock outlet of N°1
From air flushing bell of N°3
OUTLET N°2

FIG. 65.—Dosing device, Ridgewood, N. J.

Where filters of the double contact system are filled from below to a level of from 4 to 6 inches beneath the surface and are well managed freedom from odors can be maintained in a manner satisfactory to the most fastidious and to an extent not afforded by any other method of filtration available for fairly sizable plants.

COST OF CONSTRUCTION AND MAINTENANCE

Exclusive of land, outfall sewers, pumping stations, etc., contact filters by themselves cost per acre from $15,000 to

$35,000, depending upon the amount of excavation, the size and design of the individual filter units and the cost in place of suitable filtering material. Where false bottoms are used and units are built about 5 feet deep, arranged as primary and secondary beds and with at least three complete sets of units, the ordinary cost per acre may be given roughly at $35,000. This does not include, of course, any tanks for preliminary treatment, intermediate nor final treatment, nor any sand filters nor sterilizing arrangements.

The best cost of data as to maintenance are probably available from Plainfield, N. J., for the past few years. The following costs are taken from a recent report of the author and have been confirmed by Mr. Gavett.

TABLE 95.—COST OF OPERATION OF PLAINFIELD SEWAGE DISPOSAL PLANT

Item	1907	1908	1909	1910
Manager-chemist, consulting engineers	.....	$1,325.50	$1,818.46	$1,677.67
Night operator	$ 540.00	.....	.....	.....
Laboratory	41.69	247.87	147.18	80.72
Tools and supplies	23.02	103.45	32.63	8.28
Labor	50.59	53.70	.....	.....
Water guarantee	73.20	73.20	73.20	.....
Telephone	43.99	25.08	28.58	23.05
Care of contact beds	1,180.53	1,189.26	885.09	918.68
Care of septic tanks including emptying and disposal of sludge	662.25	603.50	252.89	269.17
Grading and weeding banks	104.22	.....	.....	.....
Screen attendance	.....	193.14	298.30	312.23
Farming	236.15	.....	.....	.....
Total	$2,955.64	.....	.....	.....
Farm products receipts	248.65	.....	.....	.....
Total cost of maintenance	$2,706.99	$3,814.70	$3,536.33	$3,289.80
Improvement of contact beds	.....	.....	$2,032.87	$ 935.36
Repair of septic tanks	101.14	.....	151.89	1,011.15

RÉSUMÉ

Double contact beds of fairly coarse material, when fed from the bottom, provide the best available practicable method of rendering ordinary sewage non-putrescible without likelihood of offensive odors. There are several suitable devices for the reliable automatic control of their operation. Final or intermediate settling basins are desirable even when the beds receive a fresh, well-clarified sewage. For bacterial purification in excess of 80 to 85 per cent. the final effluent should be sterilized or applied to sand beds.

As compared with sprinkling filters, contact beds are much more expensive, owing to the comparatively low rate of filtration, averaging not more than about 600,000 gallons per acre daily. In some cases it is cheaper, however, to build contact beds than to deliver the sewage to areas sufficiently isolated to permit of the satisfactory use of sprinkling filters.

Contact beds are usually cheaper than intermittent sand filters when the latter are built artifically for towns having at hand no areas of suitable sand in place.

CHAPTER XXI

SPRINKLING FILTERS

Sprinkling filters provide for the application of sewage in a comminuted form, usually as a spray, to fairly thick layers of coarse material resembling in size that of contact filters. In accomplishment they also resemble contact filters as distinguished from sand filters, in that the effluent is non-putrescible, although by no means free of suspended matter, bacteria or organic matter. Essentially this type of filtration is applicable for the elimination of nuisances due to the decomposition of the organic matter in sewage rather than to the substantially complete removal of objectionable bacteria. For the latter purpose they are of use and can be supplemented by combination with other methods.

NOMENCLATURE

This style of filters is sometimes spoken of as "sprinkling filters," "percolating filters," "trickling filters," "intermittent-continuous filters," "oxidizing beds," "bacteria beds," or "biological filters." The last three expressions are not distinctive, as already explained in connection with contact beds. "Intermittent-continuous filtration" has technical merit to support it, but it is not an expression in common use. "Percolation" is used by many engineers synonymously with "filtration," and for this reason the expression "percolating filters," although used by quite a number of persons, is not in general favor in America. "Trickling filters" is not an objectionable expression, but is considered by the author as less preferable than "sprinkling filters," which is the term that has been applied by engineers in this country to the great majority of practical projects involving this method of treatment.

HISTORICAL DEVELOPMENT

Lawrence Antecedents.—In June, 1889, two filters of gravel stones were put in operation at the Lawrence Experiment Station of the Massachusetts State Board of Health. The

stones in one of these filters were of a size that would pass through a mesh 0.375 inch square, but not through a mesh 0.125 inch square. The other filter was of coarse gravel, the stones being of a size such that none were less than 0.75 inch in diameter nor more than 1.25 inches. These filters yielded data on which was based one of the most important turning points in the history of modern sewage purification. They led to the oft-repeated conclusion as stated in the Lawrence reports as to the essential feature of sewage purification, namely, "the slow movement of the liquid in films over the surface of the stones in contact with air." They served as the foundation for the modern sprinkling filter, as well as for the modern contact filter.

English Origin.—As was the case with contact filters, the sprinkling filter also was developed to a practical basis in England, where great effort was made to utilize high rates for sewage filters. In a small way attention was given at Lawrence to means of applying sewage to gravel filters, but it is principally Mr. Joseph Corbett, for many years City Surveyor of Salford, England, to whom we are indebted for practical advances upon the Lawrence gravel filters, with respect both to means of application of the sewage as a spray and the use of false bottoms to minimize the effect of clogging upon the filter floors.

Stoddard and Waring.—It is true that Mr. Stoddard published earlier than did Mr. Corbett the results of contemporaneous tests in purifying sewage with devices for the application of the liquid in the form of drops over the surface of a filter of coarse material. It is also true that in 1891 the late Col. George E. Waring obtained a patent on a process involving filtration through coarse material with the aid of forced aeration. Elaborate experiments by Col. Waring were made at a testing station constructed and operated by him during 1894 at Newport, R. I., and tests along more or less similar lines were conducted for a term of years at the Lawrence Experiment Station.

American Beginnings.—Based on observations as to accomplishments with sprinkling filters in Europe, particularly at Salford, Accrington and Leeds, the first sprinkling filter installation was recommended for adoption in America at Atlanta, Ga., by Mr. Rudolph Hering in January, 1903. Funds were not provided until 1910 for construction. In 1901, however, a small filter plant was installed at Madison, Wis., where sewage was applied to a coarse-grained filter through lines of perforated

tile pipe laid about 2 feet apart. These distributing pipes at Madison were placed below the surface of the filter, over which during winter there was sometimes placed a covering of hay.

The Waring device including forced aeration was installed at Willow Grove, near Philadelphia, Pa.; Wayne, Pa.; East Cleveland, Ohio; and Homewood, a suburban district of Brooklyn, N. Y.; but it did not meet with practical success on account of the excessive cost with respect to the aid secured from forced aeration. In those days considerable timidity was felt by American engineers as to the utility of methods involving the application of sewage in a comminuted form, especially during the winter months in northern climates.

Practicability in Winter.—The Columbus sewage testing station played an important part in the development of this process in America through the demonstration of the practicability of operating sprinkling filters during severe winter weather, and in obtaining a non-putrescible effluent at much less cost for construction and operation than was hitherto considered feasible with contact filters or otherwise. Those tests were conducted with broken stone screened between sizes of about 0.50 and 2.0 inches. Some apprehension was then felt as to the clogging of these materials and the possibility of having to remove the filtering material at intervals for washing and cleaning. The experiments conducted at the Institute of Technology, Boston, Mass., and other information, led to the elimination of the finer particles of filtering material and anxiety on this score has gradually disappeared, particularly with the knowledge of the behavior in practice of the first municipal sprinkling filter put in service in America, namely, the plant at Reading, Pa., in January, 1908.

Later Data.—Much valuable information from test devices since the early work at Lawrence, Columbus, and Boston, has been forthcoming from testing stations at Lawrence and Boston, Mass.; Waterbury, Conn.; Baltimore, Md.; Gloversville, N. Y.; Philadelphia, Pa.; and Chicago, Ill. All of this has aided in our present understanding of this epoch-making method of obtaining a non-putrescible effluent at low cost. Since this method of sewage purification has been the one recommended for practically every large purification project since the completion of the Columbus tests in 1905, it is not unnatural that substantial progress has been made by various designers and operators as to

numerous details, some of which will be outlined hereafter. The most important single feature, however, has dealt with means for the application of sewage uniformly to the filter surface.

Present Status.—Sprinkling filters, by themselves, are not normally a complete working process, yet they constitute the greatest step in advance during the first half decade of this century in the field of sewage purification in America. Highly important work has since been done and is being now done in adapting them for most advantageous use with other steps in sewage treatment, all with a view to minimizing odors and securing reliability of performance at least cost. They are far more economical than intermittent sand filters or contact filters. Unless the sewage is fresh they are likely to produce more odor around the plant than are contact filters, and hence they are usually isolated to a greater extent than contact filters.

EXTENT OF USE

The first modern sprinkling filter plant for municipal use in America was designed in 1905 under the immediate charge of Mr. John H. Gregory for Columbus, Ohio. Mr. Julian Griggs was Chief Engineer and Messrs. Hering & Fuller, Consulting Engineers. As already stated, what might be called a "trickling filter" was installed in 1901 at Madison, Wis., but practical developments in America with sprinkling filters may be said to date from the work at Columbus. During the construction of that plant, 10 acres in area, the first one-acre unit of the sprinkling filter plant at Reading, Pa., was put in service in January, 1908. This was built by Mr. O. M. Weand, Contractor. Mr. E. H. Beard was City Engineer of Reading and Messrs. Hering & Fuller were Consulting Engineers. In November, 1908, the Columbus plant went into service, as was the case with the small sprinkling filter plant at Washington, Pa. The sprinkling filters at Mount Vernon, N. Y., were completed late in 1910 and the Baltimore, Md., installation of 14 acres was practically completed in 1911. They have been adopted at Waterbury, Conn.; Gloversville, N. Y.; Pennypack creek district, Philadelphia, Pa.; three plants at Atlanta, Ga.; Batavia, N. Y., and at several smaller places.

The above list is by no means complete, and plans for sprinkling filters have been prepared without active steps having yet been taken toward installation at numerous other places, among

which may be mentioned York, Allentown and Meadville, Pa.; Rome, N. Y.; North Plainfield, N. J., and numerous smaller places.

EFFICIENCY

Sprinkling filters when operated under favorable conditions are capable of removing from 70 to 90 per cent. of the applied bacteria, although the latter figure is reached only in instances of deep beds of fairly fine material. Occasionally growths of harmless species obscure the true efficiency. Filters of this type, as ordinarily used with fairly coarse material, are not good clarifiers of sewage. In fact, if they are such, they will clog and involve much expense for cleaning. However, they will reduce and modify the character of the suspended matter so that much of it appears as a fairly coarse granular substance which readily subsides in settling basins.

The main province of the sprinkling filter is to reduce the non-settling colloidal and dissolved organic matters to a point where the effluent will no longer putrefy or decompose anaerobically. From this viewpoint sprinkling filters are a great success in that at high rates they will allow a stable non-putrescible effluent to be obtained, with little or no likelihood of serious complications from clogging. Various factors in the construction and operation of the filters and in the character of the applied sewage have much to do with the quality of the effluent, as is well shown in the results obtained at various testing stations. They are probably reviewed most comprehensively by Messrs. Clark and Gage in their recent reports on this and other subjects in the investigations at the Lawrence Experiment Station of the Massachusetts State Board of Health. These reports and those of other testing stations should be thoroughly read by those who wish to become familiar with the full details of the present evidence on this subject. We shall confine ourselves here to the results obtained in practice from the large sprinkling filter plants at Columbus and Reading.

Reading.—The Reading plant is now composed of three one-acre filter units, one of which (No. 4), containing 5 feet of broken slag, was put in service in January, 1908. Another unit (No. 2) containing 6 feet of broken feldspar, was put in service late in 1909. The third unit (No. 1) was completed in the autumn of 1911 and closely resembles the first unit (No. 4). Each of these

three filter units has its own respective settling basin for the effluent of a size corresponding to about three hours' average flow. Mr. E. Sherman Chase, Chemist-in-Charge of the Reading plant, has furnished annual averages of daily results, as shown in Table 96. Further details of the Reading results are to be found in the *Engineering Record* of Sept. 25, 1909; Aug. 13, 1910; and Apr. 22, 1911. The putrescibility tests beginning with 1910 have been made with methylene blue, incubated for one week at room temperature. Oxygen consumed has been determined by the Kubel method with a 5-minute boiling period. The rates of filtration averaged about 2.35, 2.23, 1.94 and 2.30 million gallons per acre daily in 1908, 1909, 1910 and (Jan. to Sept.) 1911, respectively. After the third unit went into service in Oct., 1911 the average rate was about 1.5 million gallons per acre daily.

TABLE 96.—ANNUAL AVERAGES OF DAILY ANALYSES OF THE INFLUENT AND SETTLED EFFLUENT OF THE READING SPRINKLING FILTERS IN PARTS PER MILLION

		1908	1909	1910	1911
Turbidity:	Screened sewage	165	157	169	151
	Filter influent	57	64	88	102
	Effluent, settling basin 4	24	24	18	18
	Effluent, settling basin 2	.....	.....	19	19
	Effluent, settling basin 1	.....	.....	.....	14
Oxygen consumed:	Screened sewage	58	56	51	38
	Filter influent	26	28	30	28
	Effluent, settling basin 4	15	12	14	17
	Effluent, settling basin 2	.....	.....	15	14
	Effluent, settling basin 1	.....	.....	.....	13
Nitrogen as nitrates:	Effluent, settling basin 4	4.6	6.9	5.5	5.3
	Effluent, settling basin 2	.....	.....	5.1	5.7
Dissolved oxygen:	Effluent, settling basin 4	5.8	7.0	6.4	6.4
	Effluent, settling basin 2	.....	.....	6.4	5.9
Putrescibility:	Effluent, settling basin 4	0	0	0	0
	Effluent, settling basin 2	.....	.....	0	0
	Effluent, settling basin 1	.....	.....	.....	0
Bacteria per cubic centimeter, (Millions):	Screened sewage	3.48	2.07	2.43	2.80
	Filter influent	1.50	1.90	1.32	1.63
	Effluent, settling basin 4	0.63	0.40	0.33	0.36
	Effluent, settling basin 2	.....	.....	0.48	0.31
	Effluent, settling basin 1	.....	.....	.....	0.71
Per cent. of total bacteria removed:	System 4	82.	81.	86.	87.
	System 2	.....	.....	80.	89.
	System 1	.....	.....	.....	73.

Columbus.—This 10-acre sprinkling filter plant was put in service in the autumn of 1908. It was excellently described in a paper by Mr. John H. Gregory in the *Transactions of the American Society of Civil Engineers*, Vol. LXVII, page 206. It receives the sewage in a more or less advanced stage of decomposition after its passage through a septic tank, with results as shown on page 471. The average sewage flow has approximated 13 million gallons daily. As actually applied to the filters in service, the rate has been about 3.5 million gallons per acre daily, or between two and three times the average. Mr. Clarence B. Hoover has kindly furnished the average results for the past three years, as shown in Table 97. The Third Annual Report of the Division of Sewage Disposal, Mr. W. W. Jackson, Superin-

TABLE 97.—ANNUAL AVERAGES OF DAILY ANALYSES OF THE INFLUENT AND EFFLUENT OF THE COLUMBUS SPRINKLING FILTERS

			1909	1910	1911
Suspended matter in parts per million:		Septic effluent	82	80	99
		Filter effluent	84	79	96
		Settling basin effluent	41	50	38
Permanganate oxygen consumed in parts per million:		Septic effluent	38	34	31
		Filter effluent	21	20	18
		Settling basin effluent	19	17	18
Dissolved oxygen consumed in parts per million:		Septic effluent		73	95
		Filter effluent		23	25
		Settling basin effluent		27	19
Final effluent:	Parts per million:	Chlorine	56	68	99
		Dissolved oxygen	5.8	7.7	.....
		Nitrogen as nitrite and nitrate	3.35	4.00	4.63
		Nitrogen as nitrite and nitrate after 24 hours at 37° C	2.34	2.00	1.66
		Dissolved oxygen after 24 hours at 37° C.	.64	1.00	.26
	Methylene blue: days required to decolorize at 37° C.		4.8	3.9	3.5
Whole numbers of bacteria in millions per cubic centimeter:		Septic effluent	1.05	1.71	1.85
		Filter effluent	.56	.65	.56
		Settling basin effluent[1]	.74	1.50	1.09
Percentage removal of total bacteria by system			74.	79.	81.

[1] Growths of harmless species of bacteria in the final settling basin cause at times a lower apparent removal for the entire system than would be true if the final settling basin were omitted.

tendent shows further details, particularly as to the maximum and minimum as compared with the average results. As described by Mr. Hoover in *Engineering News* of Mar. 16, 1911, the permanganate oxygen consumed is obtained with a 5-minute boiling period, and the dissolved oxygen consumed is noted by changes in the atmospheric oxygen in diluted samples after incubation for 24 hours at 37° C.

CAPACITY

The capacity of sprinkling filters to purify sewage depends upon the strength of the sewage, the size and depth of the filtering material, and the quality of effluent which it is desired to secure, particularly in the winter in severe northern climates.

The Columbus plant, with an effective depth of 5 feet of material above the coarse stone surrounding the underdrains, was rated at a capacity of 2 million gallons per acre daily on an average. At Baltimore it was concluded in 1906 to specify filters with a depth of 9 feet and a size of stone of 1.0 to 2.5 inches at an average rate of 2.5 million gallons per acre daily with a sewage estimated to average about 125 gallons per capita daily.

The practice of the author recently has been to specify for average conditions a 6-foot filter at an average rate of about 2 million gallons per acre daily. This would be for a sewage flow of separate sewers approximating 100 gallons per capita daily. Where it is necessary to secure a high-grade of purification during the winter months in a severe climate the recent tendency has been to lower this rate somewhat, depending upon local conditions.

Mr. Eddy recommended in 1910 for East Orange, Montclair, etc., N. J., an average rate of 2 million gallons per acre daily, corresponding to a sewage flow from 15,000 people for sprinkling filters having a depth of 7.5 feet. At Gloversville, N. Y., where there is much tannery waste in the sewage, he recommended for an average sewage flow of 3 million gallons daily, 3.07 acres of sprinkling filters with 5 feet in depth of material ranging in size from 1.5 to 2.5 inches. Furthermore, these filters will be followed by 2.71 acres of sand filters for further purification of the effluent.

The conclusions in Mr. Webster's Philadelphia Report of 1911 favor a 6-foot bed at a rate of 2.5 million gallons per acre daily.

In Mr. Wisner's Report of Oct. 12, 1911, upon Sewage Disposal at Chicago, sprinkling filters of an average depth of 6 feet 4 inches were rated at 2.5 million gallons per acre daily, corresponding to a population of about 10,000 people per acre.

It is thus seen that while a 6-foot filter, operating at an average rate of 2 million gallons per acre daily, may be taken as normal practice, the present tendency is to increase this rate somewhat for deeper filters and very weak sewage, but to decrease it to offset the influence of local conditions as to winter weather, trade wastes, street wash, etc.

Compared with contact filters it may be said that sprinkling filters give approximately equal efficiency with a rate of filtration three to four times as high as those described in the preceding chapter on Contact Filters. This seems to be explained, as will be mentioned later, by the benefits resulting from the aeration of the influent and the constant providing of oxygen within the filter.

INFLUENCE OF STRENGTH OF SEWAGE

The yields of sprinkling filters in America where the sewage is ordinarily very dilute, is strikingly higher than those with the European beds receiving strong sewage. In fact, the rates in America are roughly double those in Europe, where the sewage is roughly twice as strong.

Within certain limits the average rate of filtration of the sprinkling filter should be adjusted to the strength of the sewage. Other things being equal, this type of filter seems to be capable of handling an approximately constant number of units of organic matter, per unit area or per unit volume of material, regardless of the per capita dilution of the sewage within the limits ordinarily encountered.

RELATION TO PRELIMINARY AND FINAL TREATMENT

Preliminary Treatment.—For the sake of guarding against clogging of the sprinkler nozzles and the surface of the filter beds it is wise to free the applied sewage, so far as practicable, of suspended matters. It is true that with weak American sewages that have been freed from grit and coarse matters by screening satisfactory results may be obtained as to efficiency without preparatory treatment to the normal extent. This was

pointed out by Profs. Winslow and Phelps several years ago at Boston, and has been recommended by the author in instances where for special local reasons it was not desired to pass the sewage through sedimentation tanks. Generally speaking, however, it is the best practice first to pass the sewage through adequate sedimentation tanks and protect the filters from floating scum and gas-lifted sludge. The reason of this is that it is considered more economical for the process as a whole to clarify the sewage before filtration. In this connection reference is made to fine screens at Atlanta and Baltimore, mentioned on page 387, and to the roughing filters being constructed at Atlanta, as described on page 581. Mr. Watson, of Birmingham, England, has used both Dortmund tanks and roughing filters to clarify the influent to the sprinkling filters of the large works, of which he is chief engineer.

Final Treatment.—A successful sprinkling filter should show as much suspended matter on an average in the effluent as in the influent. Films of organic matter more or less reduced in putrescibility are detached in an irregular way from the surface of the particles of filtering material. This causes the effluent to be unsightly in appearance, and while the liquid and solids taken together usually show a stable result, yet it is found that the solid matters when separated from the liquid will frequently putrefy. In some cases, as at Atlanta, final settling basins have not been provided as the sprinkler effluent discharges into a muddy stream. But in the great majority of cases sprinkling filters have been provided with small settling basins holding from one to three hours' flow through which the effluent may pass and be freed of coarse suspended matter. At Reading the sludge approximates about 2 cubic yards per million gallons with a water content of about 95 per cent. Notwithstanding that the effluent of the filter is well oxygenated, the sludge on the bottom of these final settling basins will gasify and cause masses to pass to the outlet unless much care is taken to clean the basins at intervals of about one month in the summer. In winter the interval may be three months. Recently the author has recommended two story septic tanks to serve this purpose, and also in another case a tank of the Dortmund type, with a view to separating the sludge and returning it to the main sedimentation tank to undergo septicization.

CHARACTERISTICS OF PROCESS

The process by which sprinkling filters do their work shows many points of similarity to contact filters, but there are also several features in which there is a difference. Reference is here made to this topic as outlined in the preceding chapter which we will supplement with a brief outline of the characteristics of sprinkling filters, as follows:

Time Factor.—Much less time is occupied by the sewage in passing through sprinkling filters than contact filters. If the material is coarse, the period is but a few minutes; frequently less than five. It suggests at once the importance of purifying agencies that are almost instantaneous in their action.

Aeration.—As the influent enters the surface of a sprinkling filter, particularly where sprayed from nozzles, the liquid is usually from 60 to 80 per cent. saturated with atmospheric oxygen. Practically without exception this has been the case at Reading. At Columbus this holds true during the colder season of the year, but, at times during the summer, anaerobic decomposition has proceeded so far that the liquid leaving the septic tanks absorbs at once practically all the oxygen which reaches it during aeration at the filter nozzles. It is much better to have the sewage fresh as at Reading.

Absence of Anaerobiosis.—When a sprinkling filter is working under favorable normal conditions, anaerobic decomposition of organic matter is of little importance.

Intermittency.—It is not imperative to apply sewage intermittently to sprinkling filters provided sufficient atmospheric oxygen is present within the filter at all times and all places. Intermittency is practised to increase the actual rates of flow through the sprinkler nozzles and thus lessen the chance of clogging, to promote ventilation through the draining of the liquid from the bed, and to facilitate an even distribution of liquid over the filter surface.

Ventilation.—As this process requires all steps to be taken on an oxidizing basis so far as practicable, aid is received from the movement of air vertically from top to bottom or from bottom to top of the filter.

Surface Clogging.—Surface clogging if of long duration materially interferes with the normal behavior of sprinkling filters as regards capacity or efficiency or both. The effort is made to secure material of sufficient size and stability to eliminate

pooling of the liquid upon the surface due to solid matters removed from the influent. Vegetable growths in summer and the formation of ice during severe winter weather may appear. The former may be corrected by the application of germicides. In some severe climates ice may not be sufficiently bothersome to call for covers, but in designs for such locations if the filters are uncovered a factor of safety should be allowed as regards the capacity and efficiency of the plant.

Resting.—If sprinkling filters are not overworked and oxygen is present at all times and places within the beds, resting is not a factor of much importance; certainly not to such an extent as with contact filters. In fact, while resting promotes the removal of stored matters during the warm season of the year, it is a distinct disadvantage during the cold season for beds of coarse material. Nitrifying processes are seriously interrupted and it may take a long time to restore the plant to its normal regimen of operations.

Worms.—A marked characteristic of this type of filter is the growth within the filtering material of enormous numbers of several varieties of worms which undoubtedly play a considerable part in the elimination of organic matter. Different species are found at different plants. The most prevalent ones seem to be the larvæ of moth flies. These white "worms," or "maggots," form an abundant food supply for hornets and wasps that search the interstices of the filtering material for them, and kill, eat or bury them for future food supply. At the sewage plant at Mount Vernon a species of red worm somewhat resembling but considerably smaller than the common earth worm was found in large numbers.

Flies.—Flies are very numerous around the ordinary sprinkling filter. They are not the ordinary house flies, but a moth fly (Psychoda alternata). They are seldom found more than 100 yards away from the filters.

Unloading.—One of the most marked characteristics of coarse-grained filters of the sprinkling type is their ability to discharge the retained solid matters and for this reason they may continue in service at high rates year after year without becoming clogged. In fact, on an average there is as much suspended matter found in the effluent of sprinkling filters as in the influent, generally speaking. Some suspended organic matter is no doubt converted to dissolved mineral substances, but the influence of

this seems to be more or less obscured by the presence in the effluent of the bodies of large organisms.

Dissemination of Bacteria in Air.—As a result of throwing as a spray large volumes of sewage in the air above the surface of sprinkling filters, it has been suggested that sewage bacteria might be disseminated in the air so as to produce a condition prejudicial to health on the leeward side of a plant. The facts are shown to be just the opposite, according to Dr. John Robertson, Medical Officer of Health, Birmingham, England, who conducted some tests which showed that during the summer the number of bacteria in the air passing through the sprays was greater before than after such passage. He states that 50 yards away from the bed on the lee side sometimes one-fourth of the number of organisms were obtained, as compared with the number on the windward side 50 or 100 yards away. In the winter, however, the conditions were different. Then in windy weather a certain number of sewage organisms were carried over, the distance varying according to the strength of the wind. The facts were so variable that it was not possible to give representative data, but roughly it may be said that the stronger the wind the farther the organisms were carried; in no case, however, was he able to detect, with delicate tests, sewage organisms at a greater distance than 100 yards from the beds. He came to the conclusion, therefore, that any harm that might be done by such a method of distribution was practically negligible.

CHARACTER OF FILTERING MATERIAL

What has been said in the preceding chapter for contact filters under this heading applies here also, except as regards size and depth.

Size.—Experience with sprinkling filters has caused the use of a larger size of material than formerly. Theoretically, it should be as fine as will allow in practice a good circulation of air from top to bottom, but no finer. Tests at Columbus were made with a material having a nominal size of from 0.5 to 2 inches. It was feared that this would clog seriously when operated at an average rate of 2 million gallons per acre daily and for the large Columbus works the main body of material ranged nominally in the different filters from about 1.5 to 3 inches or from 1.0 to 3 inches. The former was found to have an effective size of

1.4 inches and a uniformity coefficient of 1.4. The average size of the stone was 1.7 inches as measured by the diameter of a sphere of equal volume. For the 1.0 to 3-inch material the effective size according to Mr. Gregory was 1.1 inches, the uniformity coefficient 1.6 and the average size 1.5 inches. The original Reading slag filter (No. 4), had an effective size of 1.3 inches, and an average size of 1.6 inches, and 90 per cent. of the material was less than 2.1 inches, figured as a sphere of equal volume. No. 2 unit at Reading is of stone and the above figures for its material are 1.6, 2.1, and 2.9 inches, respectively. With limestone or trap rock or coke, the longest axis of the particles is usually more than 50 per cent. greater than the mean. Beginning with the Baltimore report in 1906 the majority of sprinkling filter projects have had the materials specified to be screened between 1.0 and 2.5 inches. Recent tendencies are to screen within still closer limits, to aid in the unloading of suspended matters, where the cost does not increase the price of material too much. The author has recently specified the materials to be screened between 1.0 and 2 inches; Mr. Wisner's Chicago report of Oct. 12, 1911, mentions a size between 1.25 and 2 inches; and at Atlanta and Gloversville the material was screened between 1.5 and 2.5 inches.

Depth.—The Columbus and Reading (No. 4) filters are 5 feet in depth above the lower course of large material surrounding the underdrains. At Baltimore where an unusually high-grade effluent was desired, the depth above the underdrains is 8.5 feet. In the great majority of designs for sprinkling filter plants in America, the depth of the main body of material has been about 6 feet. Recently there has been some tendency to increase this slightly, although this is not in harmony with the conclusions of the Philadelphia Report of 1911. As described by Messrs. Clark and Gage in the 1910 Report of the Massachusetts State Board of Health, page 259, the quality of effluent within certain limits improves with the depth of material. Data from Lawrence and elsewhere show that within certain limits the permissible rate of filtration increases with the depth. Owing to the cost, regardless of depth, of the false bottom and the system of distribution pipes, engineers desire to make the beds as deep as they can without increasing the total cost of treatment per million gallons of sewage due to complications from surface clogging. It is a proposition which must be

worked out for different problems and the result will doubtless vary somewhat for different local conditions.

FEATURES OF CONSTRUCTION

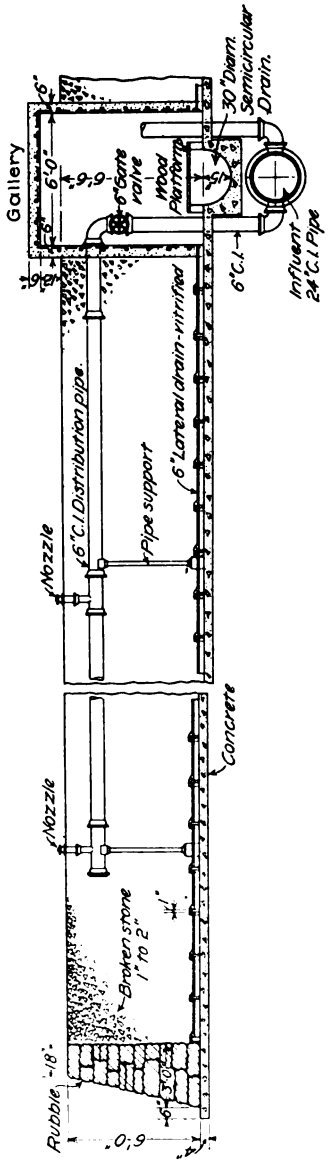


FIG. 66.—Sprinkling filters for North Plainfield, N. J.

Filter Floor.—Tight concrete floors have been provided in all American designs for sprinkling filters. The main floor slopes about 1 to 100 to the main effluent-drain in the older designs. This has been increased to about 1 to 27 in some instances, as at Atlanta, where the floor slopes to a series of drains spaced 27 feet apart.

Filter Walls.—The Columbus filters were designed with watertight concrete walls to permit of the use of the filters as contact beds should occasion arise during severe winter weather. Mr. Weand built the first Reading unit with a dry rubble wall for reasons of economy, and this is the style which has been most generally followed since that time. It is usually somewhat cheaper to build rubble than concrete walls. Some think that there is an advantage in having openings at the side to permit the lateral circulation of air. It is doubtful if there is much if any benefit to be derived from the latter feature. There is no economy in extending the filter floor to a sufficient distance beyond the surface periphery of the filter to allow the material to form a natural angle of repose. The cost of the additional filter floor,

false bottom and filtering material offsets the expense of a rubble wall. Fig. 66 shows filter walls as designed for North Plainfield.

False Bottoms.—To prevent the suspended matters in the

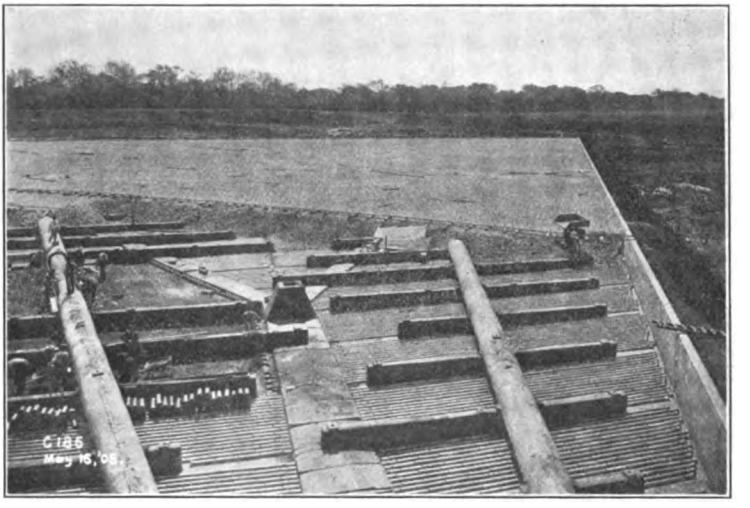


FIG. 67.—False bottom, Columbus, Ohio.

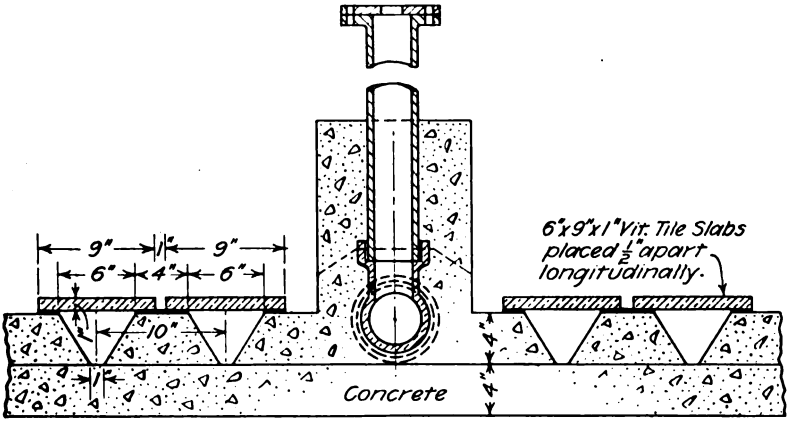


FIG. 68.—False bottom at Kings Park, L. I.

effluent from accumulating on the floor of the filter and thus interfere with ready draining and ventilation of the bed, it is highly important in all cases to provide false bottoms.

Nearly all of the older sprinkling filters have followed the practice at Columbus of securing a false bottom by embedding half-round pipe in a mortar facing to the concrete floor. At

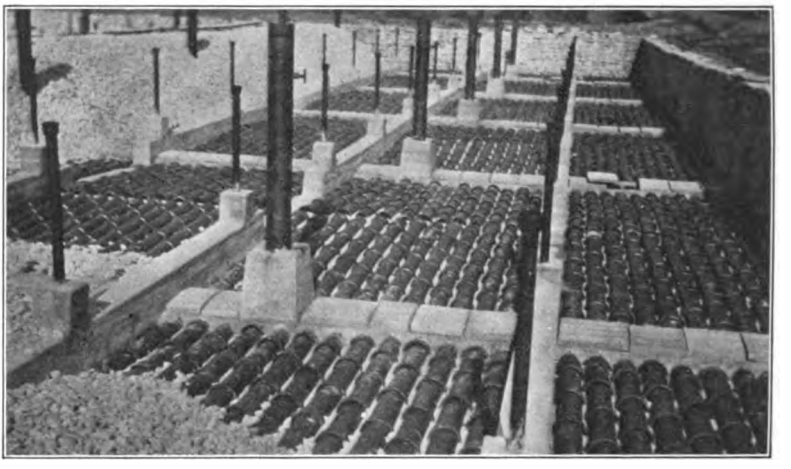


FIG. 69.—Filter floor, Atlanta, Ga.

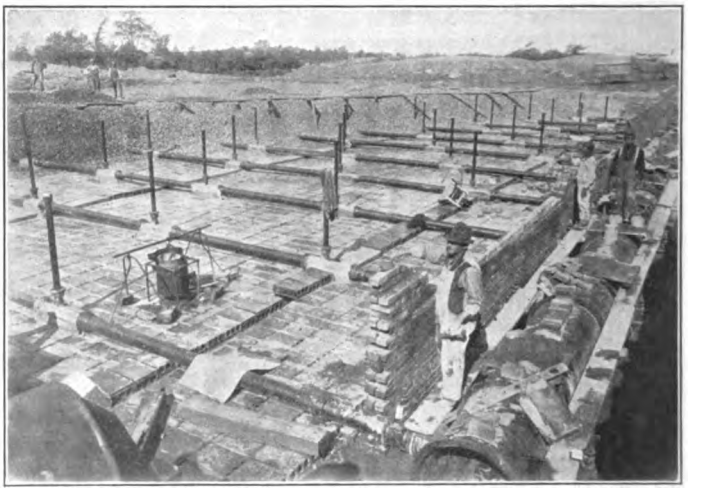


FIG. 70.—Tile filter floor, Batavia, N. Y.

Baltimore a series of channels was designed by Mr. Hendrick for the concrete floor, with perforated tile covers for these channels. Fig. 67 shows a view of the false bottom of the Col-

umbus filters, furnished through the courtesy of Mr. Gregory. Fig. 68 shows a section through the waterways in the concrete bottom of the Kings Park filters, with overlying tiles laid with open joints. Fig. 69 by courtesy of Mr. Hansell shows the filter floor of the Proctor creek (Atlanta) plant as built in alternate ridges and hollows.

Quite recently the American Clay Products Co. has put upon the market a vitrified tile channel to serve both as a floor and false bottom. Fig. 70 shows a view taken by Mr. Hoopes of this type of bottom under construction at Batavia, N. Y., and furnished by Mr. Gregory. The tile channels are properly bonded together, and there are perforations through the upper face to provide an entrance for the effluent to the waterways leading to the main drains.

Ventilators and Cowls.—Fig. 71, by courtesy of Mr. Hansell, shows a view of ventilators being installed in the Atlanta sprinkling filters for the purpose of promoting a vertical circulation of

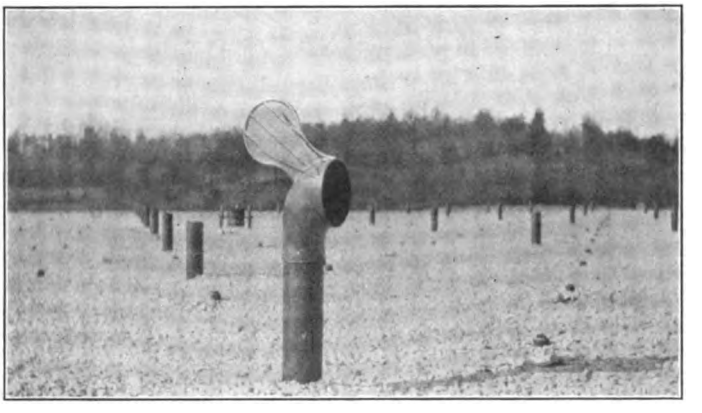


FIG. 71.—Ventilating cowl, Atlanta, Ga.

air through the filter. On top of these ventilating pipes are cowls which automatically turn toward the wind. There is a difference of opinion as to the need of these arrangements which, however, are of but little cost. As installed at Atlanta they call for an arrangement of the underdrains and false bottoms which results in an unusually large portion of the filter being above waterways in which there is comparatively little flow and which are inaccessible for ready cleaning or flushing. With

filters of fine material data at Lawrence show that there is likelihood of exhaustion of oxygen and accumulation of carbonic acid within the lower portions of the filter. This is highly undesirable and is to be guarded against. On the other hand, if the filtering material is coarse enough to allow a circulation of air from top to bottom and vice versa, these is not much reason for believing that ventilators are necessary. If a little oxygen is present in the atmosphere within the filter at all times and all places, it will do as much good as if the atmosphere were saturated with oxygen. At Salford, England, and Leipsic, Germany, the opinion is held that artificial ventilation is of importance. These views are also held by Mr. Rudolph Hering.

Operating Gallery.—In the report to the Board of Advisory Engineers at Baltimore in 1906 a preliminary design was shown for sprinkling filters in which, at the sides, was a closed gallery. The purpose of this was two-fold: partly to aid in ventilation and partly to give accessibility to the head of the different lines of half round pipe in the event that it should be necessary to flush or otherwise dislodge the stranded particles between the false and true bottoms. The second installation at Reading, designed by Messrs. Hering & Fuller in 1908, shows (Fig. 72) a central operating gallery in which accessibility for flushing the waterways beneath the false bottom is provided; and an opportunity is also given for controlling the gates on each influent pipe line. The Reading design was prepared to meet the possible necessity for shutting off portions of the bed due to vegetable growths upon the surface of the filter. The successful use of hypochlorite of lime in destroying these growths has reduced somewhat the need for these central galleries as shown above. They have been embodied, however, in quite a number of later designs.

Influent Piping.—At Columbus and practically all of the earlier sprinkling filter plants the influent lines consisted of vitrified pipe encased in concrete. Uncertainty as to possible leakage, particularly at the joints where there are attached the risers connecting with the nozzles, has led in later designs to the use of cast-iron pipe for this purpose. Fig. 73 shows a view of the influent piping arrangements of the Peachtree creek plant at Atlanta, designed by Messrs. Hering & Fuller.

Covers.—With few exceptions covers have not been provided for sprinkling filters. It has been generally found to be cheaper to extend the area of the filters to make allowance for inter-

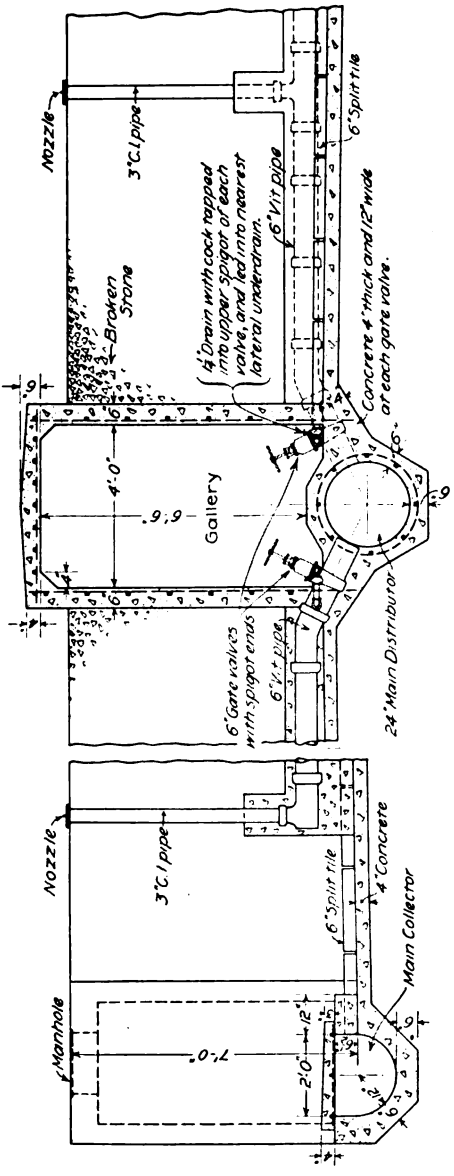


Fig. 72.—Sprinkling filter details, Reading, Pa

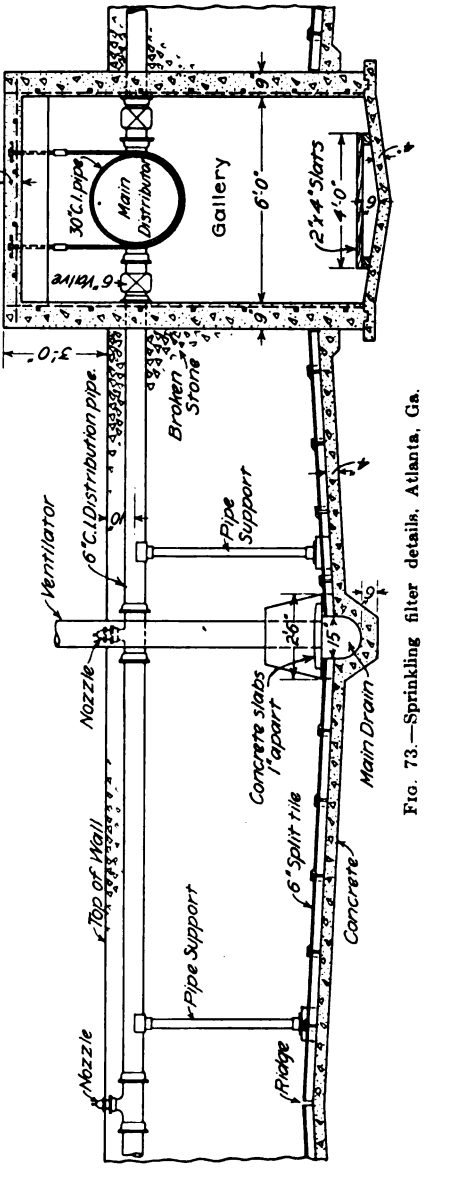


Fig. 73.—Sprinkling filter details, Atlanta, Ga.

ruptions in normal service during winter weather, rather than to build covers to protect against severe cold. At Gloversville, N. Y., however, Mr. Eddy has provided, in that severe winter climate, for wooden structures with which to cover the sprinkling filters during the winter, and which will be taken down and stored during the warm season of the year. At Mount Vernon, N. Y., is a sprinkling filter designed by Messrs. Farley and Robinson which has a permanent cover. This is partly to facilitate the use of dashplates for the distribution of sewage, and partly with a view to minimizing odors due to offensive gases. As a feature of the design for reducing odors it was proposed to operate fan blowers to remove the air from the filter buildings from time to time and discharge it through towers containing iron oxide filings. These devices have never been used. In the *Engineering Record* of Apr. 29, 1909, page 464, will be found a description of this plant.

Head Required.—In most sprinkling filter plants a head of from 12 to 15 feet is required for the application of sewage to and through sprinkling filters operated with fixed nozzles or spray jets. A head upon the nozzles of about 5 to 8 feet is ordinarily provided, and to this must be added the depth of filtering material and underdrains, the friction in the influent piping and the slope in the filter floors and effluent drains. Naturally there is some difference in the loss of head in different plants owing to different conditions, the size of installation, etc. Where revolving sprinklers are in use rather than spray jets the loss of head may be somewhat below the range in figures above given.

Distributing Devices.—There are three general arrangements for the application of sewage to sprinkling filters, namely traveling distributors, fixed sprinkler nozzles and dash-plates. The former are in wide use in Europe and are probably more efficient for applying sewage uniformly over the area of the filter surface than the other devices. They have been installed for testing purposes at Baltimore, Md., and Andover and Lawrence, Mass., but so far as we recall they have never been used for large works in this country. In the Southern states climatic conditions would not seriously interfere with their use, but generally speaking engineers have hesitated to install them on account of interruptions in service by snow and ice during severe winter weather, or the expense of housing the filters. Taking everything

into account the sprinkler nozzle is generally considered to be the most satisfactory means of application of sewage to sprinkling filters under most American conditions. The past few years have seen much attention given to the study of improved arrangements for securing a uniform distribution of sewage in filters of this type. Credit for systematic methods of studying the evenness of distribution is due largely to Prof. Phelps, who describes the results of important tests in *Engineering News* of Oct. 18, 1906, page 410. In considering these results, however, it is well to bear in mind that in practical works the wind is of considerable aid in offsetting the effect of irregularities in application. Furthermore, although some sewage may pass through at an excessively high rate of flow, the mixed effluent shows a dilution of this portion of the sewage with other parts of the liquid which have passed through the bed at a low rate and are correspondingly improved in quality. This comment is not intended to indicate, however, that it is not important to secure as even distribution of sewage upon

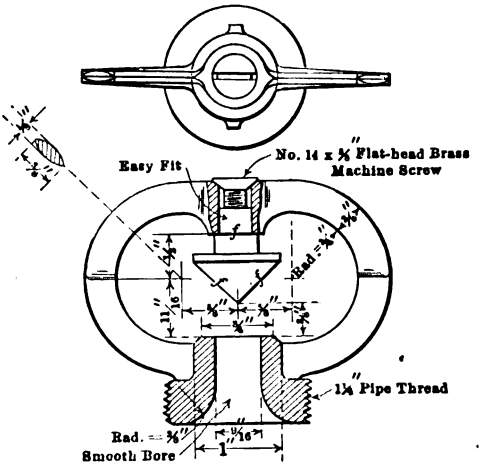


FIG. 74.—Sprinkler nozzle, Columbus, Ohio.

the surface of the filter as is consistent with economical methods of installation and reasonable assurance of reliable performance at times of heavy snowstorms and protracted periods of zero weather in the northern states.

Dr. Dunbar, of Hamburg, has used with success graded layers of carefully selected fine materials for the distribution

of sewage over coarse filtering material. This method has received but little attention in this country, as there has been apprehension as to clogging and difficulties with freezing.

Sprinkler Nozzles.—Fig. 74 shows the original nozzle designed by Mr. Gregory for the Columbus plant, the distribution of sewage by which is shown by Mr. Hoover to be as follows:

TABLE 98.—RESULTS OF TESTS SHOWING THE DISTRIBUTION UNDER DIFFERENT METHODS OF OPERATION

(The Values given are Gallons per Square Foot per Minute)

Distance from nozzle, in feet		Equal periods of time for			[1] Dosing Tank, 10 ft. to 0 ft.	Columbus nozzle, 5-ft. head. Size of orifice, in inches	
		Heads of 3 ft., 6 ft., 9 ft.	Heads of 4 ft., 7 ft., 9 ft.	Heads of 10 ft. to 1 ft.		9/16	7/16
1.0 to 1.5		0.009	0.010	0.022	0.81	0.0067	0.003
1.5 to 2.0		0.027	0.014	0.124	0.72	0.007	0.007
2.0 to 2.5		0.079	0.027	0.067	0.56	0.011	0.013
2.5 to 3.0		0.140	0.054	0.072	0.43	0.021	0.034
3.0 to 3.5		0.137	0.097	0.075	0.41	0.044	0.064
3.5 to 4.0		0.085	0.114	0.072	0.36	0.083	0.106
4.0 to 4.5		0.065	0.104	0.070	0.37	0.140	0.130
4.5 to 5.0		0.067	0.092	0.068	0.37	0.190	0.093
5.0 to 5.5		0.078	0.085	0.066	0.37	0.192	0.047
5.5 to 6.0		0.082	0.087	0.061	0.38	0.114	0.020
6.0 to 6.5		0.084	0.090	0.067	0.42	0.072	0.010
6.5 to 7.0		0.075	0.085	0.063	0.45	0.028	0.0037
7.0 to 7.5		0.070	0.079	0.061	0.51	0.011	0.0034
Means		0.078	0.080	0.066	0.43	0.078	0.039
Rate in gallons per acre per 24 hours.	Mean	4.89	5.02	4.14	.....	4.89	2.44
	Max.	8.78	6.18	7.77	.....	12.04	8.13
	Min.	0.56	0.63	1.38	.....	0.42	0.19

[1] Gallons per square foot, but not per minute.

Fig. 75 shows the Weand nozzle adopted for the original installation (No. 4) at Reading, the distribution of sewage by which is shown by Mr. Chase to be as follows, in comparison with that obtained by a modification installed by Messrs. Chiles and Witman in No. 2 unit.

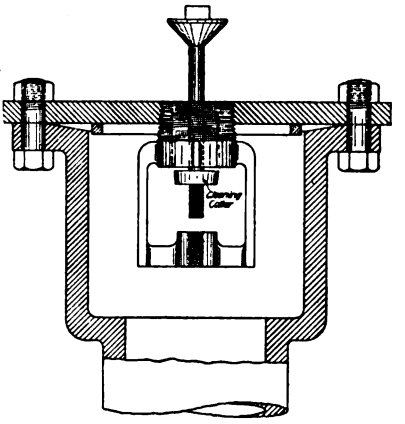


FIG. 75.—Weand sprinkler nozzle.

TABLE 99.—DISTRIBUTION OF SEWAGE, READING, PA.

Radial distance in feet	Unit No. 4 (slag) gallons per square foot per day	Unit No. 2 (stone) gallons per square foot per day
0.5	16	19
1.5	16	6
2.5	95	41
3.5	136	107
4.5	119	88
5.5	74	69
6.5	25	47
7.5	8	.....

Fig. 76 shows a Taylor nozzle sold by the Pacific Flush Tank Co. There are three types, designed to give square, octagonal and circular sprays, respectively. The former has been tried by the author at the Kings Park plant with quite satisfactory results. It has been found, however, that if these inverted cones are not kept in proper alignment they are much less satisfactory than those of the circular type. This disadvantage could of course be offset by a locking arrangement which would keep the cone in a fixed position whenever it is in place. Numerous modifications of these nozzles have been considered at Worcester, Reading and other places, but just what their relative

superiority may be we are unable to say. On the whole, the Taylor style of nozzle seems to be generally preferred to the Columbus type on account of the supporting arms of the latter aiding in the collection of grease and other particles which interfere with the uniformity of distribution. The author prefers the circular Taylor nozzle to the one with the lobed cone to cover a square area.

Nozzle clogging due to suspended particles becoming lodged in the orifice of the nozzle is a factor which requires careful consideration. At Reading about 10 per cent. of the nozzles on an average need cleaning each day. With about 250 nozzles

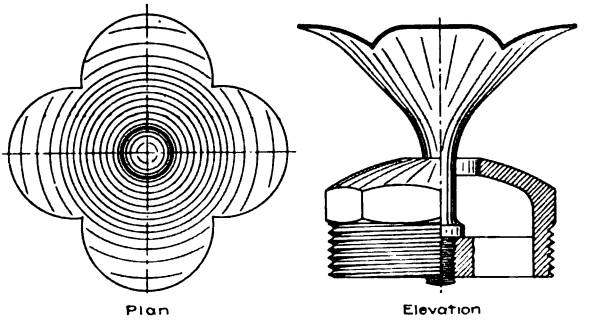


FIG. 76.—Taylor square nozzle.

per acre one man can attend to some three acres or more without difficulty. In this regard conditions are more favorable with the weak American sewages than with the strong European sewages on account of the orifices being of larger size. The size is also increased by the intermittent application of sewages, which allows of higher rates of flow than would be the case with a continuous rate of application. Nozzle clogging at times has been a very serious factor at Columbus, on account of gas-lifted particles of sludge coming from the septic tanks. Only a comparative few of the nozzles need cleaning daily when the septic tanks deliver no sludge to the filters. The use of fine screens at Atlanta and Baltimore between the tanks and filters has been largely prompted by the desire to prevent nozzle clogging.

Dashplates.—At the testing station of the Massachusetts Institute of Technology Profs. Winslow and Phelps and their associates devised an arrangement by which, instead of spraying the sewage upward from nozzles attached to riser pipes, it is

allowed to flow through a system of elevated pipes which have openings spaced at about the same intervals as are the risers for the fixed nozzle. From these openings the sewage falls upon concave disks or dashplates on which it is splashed upward and outward. This style of distribution is used in Mount Vernon, N. Y., and is described by Mr. Chas. A. Hammond in *Engineering News* for Mar. 24, 1910, page 331. It necessitates in northern climates a filter house. It is also unsuitable for ready use with a varying head such as is beneficial in securing the even distribution of sewage. When working at its best it compares quite favorably with sprinkler nozzles, but taking everything into account it is the author's belief that it is a less suitable device than the fixed sprinkler nozzles.

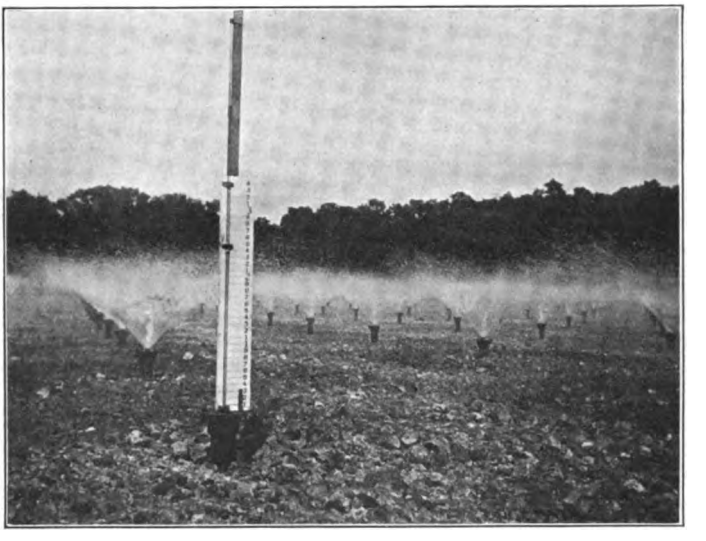


FIG. 77.—Sprinkling filter, Reading, Pa.

Spacing of Nozzles.—Suitable care should be given to the spacing of nozzles so that as uniform distribution as is practicable may be secured. Here the question of available head and loss of head in distributing piping must be considered. Speaking generally, where a head of 7 feet at the nozzle is available circular nozzles staggered and about 13.5 feet from center to center seem to give the best results. With less pressure and with nozzles throwing a square spray closer spacing is necessary.

Where possible it is advisable to allow plenty of head, as it is quite easy to reduce it later, while too little head means that part of the filter will not be properly covered by the spray. Care must be taken not to set the nozzles so close to the filter walls as to allow the sewage from the end nozzles to be thrown beyond the limit of the filter. The Taylor nozzle is fitted with a device to throw a half spray to guard against this trouble. Fig. 77 through the courtesy of Mr. Chase shows the Weand nozzles spaced on 12.50 feet centers, in operation on filter No. 4 at Reading.

Varying Head.—A fluctuating or varying head promotes evenness of distribution and in one form or another has been adopted for nearly all designs in America. The two principal

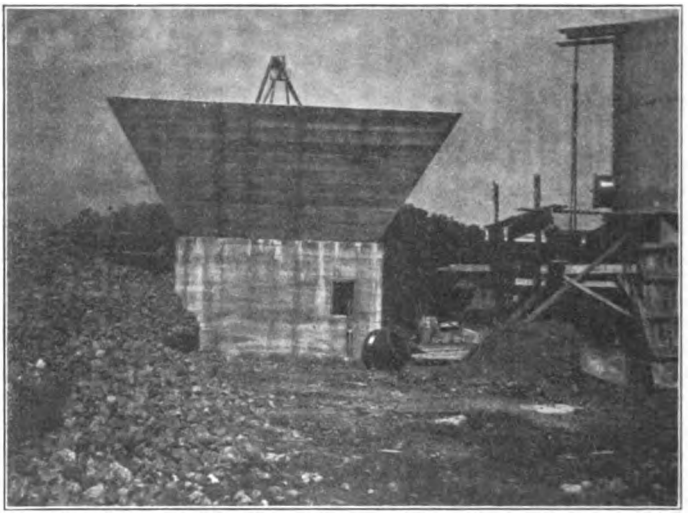


FIG. 78.—Tapered dosing tank, Reading, Pa.

methods are by means of dosing tanks and a moving butterfly valve actuated by a cam. Taper tanks have certain advantages, as developed by Mr. Taylor at Waterbury and described in *Engineering News* of Nov. 11, 1909, page 516. Fig. 78 shows an arrangement of this sort for the No. 2 unit of the Reading works for sewage discharged at intervals of about 5 minutes by means of a 24-inch Miller siphon.

Fig. 79 shows a 24-inch Miller siphon as installed for dosing the Batavia, N. Y., sprinkling filter plant. Similar devices have been installed by the Pacific Flush Tank Co. at the Proctor creek plant at Atlanta, Ga.; Gloversville, N. Y.; Reading, Pa.,

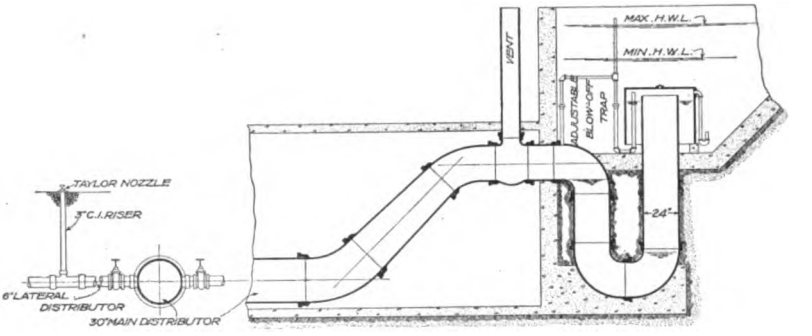


FIG. 79.—Dosing device, Batavia, N. Y.

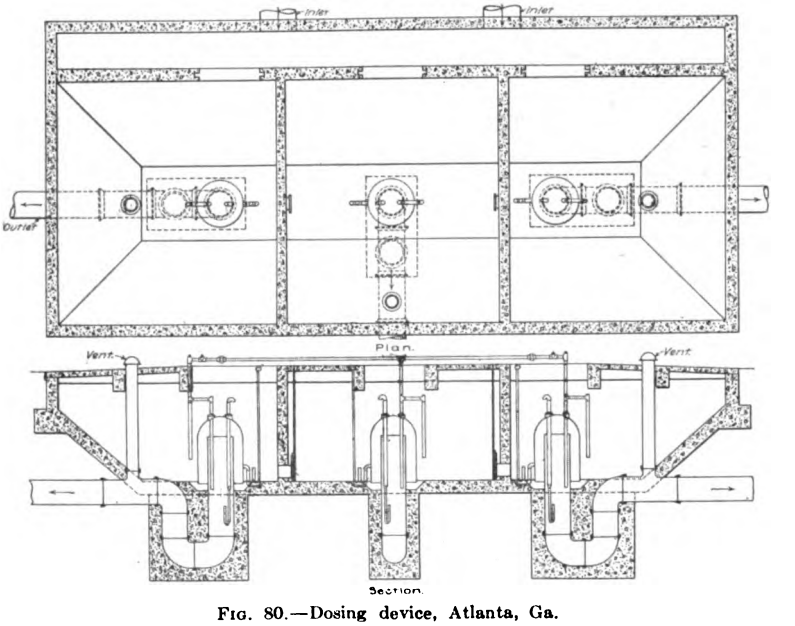


FIG. 80.—Dosing device, Atlanta, Ga.

and other places. The Batavia siphon is of rather unusual construction, as the specifications call for a range of 2 feet in the normal maximum operating head on the nozzles. Fig. 80 shows the design made by Messrs. Merritt & Co. for the Peachtree creek

works at Atlanta. This device consists of three 24-inch siphons of the Adams type, so cross-connected that any one or more of them may be operated at one time. These airlock devices are all arranged to start discharging when the sewage in the dosing tank has reached a certain maximum height and to lock at a lower level which is usually about 2 feet above the nozzle elevation.

Mr. F. P. Stearns suggested in 1906 for the Baltimore project the use of a butterfly valve to fluctuate the head of sewage on the nozzles, and this idea has been developed at the Baltimore plant and also the small plant completed in 1912 at Holmesburg, in Philadelphia. The success of this arrangement depends upon the reliability of automatic devices, either to put in service as required different cams corresponding with different rates of flow to the filters; or, by the use of float arrangements in the tanks, to actuate valves which throw into service or out of service certain portions of the influent pipe system, as needed. Mr. Taylor's paper, above referred to, contains many interesting studies at Waterbury of pressure undulating valves.

THE ODOR QUESTION

When sewage that is fairly fresh is applied to sprinkling filters there is no noticeable odor more than about 100 yards away, according to Reading experiences. With fresh sewage the odor resembles a laundry odor, or that of a raw turnip. It is not the odor of "putrefaction."

When sprinkling filters receive sewage that is in an advanced stage of anaerobic decomposition so-called putrefactive odors are conspicuous at some distance from the plant. At Columbus odors are normally noticeable not more than 300 yards away. On a few occasions, however, the odors have been objectionably noticeable at a greater distance than this, and it is claimed that on a few occasions they have been noticeable half a mile away.

Speaking generally, a sprinkling filter plant of small or moderate size should be located not nearer than 0.125 mile from built-up streets. For large plants 0.25 mile, as recommended by the Board of Advisory Engineers at Baltimore, is preferable. When a sprinkling filter treats a fairly fresh sewage that has not been allowed to undergo anaerobic decomposition, or come in contact with sludge which is so decomposed or with the products of such

decomposition, the present evidence indicates that the above limits are reasonable estimates.

COSTS OF CONSTRUCTION AND OPERATION

Sprinkling filters per acre of effective area cost from $30,000 to $50,000, depending much upon local conditions as to the cost of stone, the amount and character of excavation or embankment, the depth of bed, etc.

This figure is exclusive of the cost of outfall sewer, land, settling basins, screens, buildings, connecting pipes, etc., all of which vary more or less with different installations. An excellent summary of the detailed cost of construction of the Columbus plant was given by Mr. Gregory in his paper in the *Transactions of the American Society of Civil Engineers*, Vol. LXVII, page 206. The unit prices of Columbus work are extremely low, and they should be materially increased for most of the items, particularly concrete.

As to the cost of operation, the principal statement to be made is that with a well-constructed bed the evidence now points clearly to the permanency of the filtering material; that is, the material will clean itself and not have to be taken out and washed at intervals as was thought might be the case some years ago. One man in charge, capable of making laboratory tests of a fairly simple nature, with one helper ought to be able to take care of a plant having an area of three acres or so. Some special labor would probably be required from time to time for the care of grounds and other extra work. These attendants should also take care of well-managed final sedimentation basins in use with the filters, if some extra labor is secured from time to time during cleaning operations.

The Columbus plant was operated during 1910, according to Mr. Jackson's report, for a total cost of $9,876.66, of which sum $7,415.08 was for regular payroll and about $1000 for unusual repairs and extensions. The volume of sewage pumped during that year amounted to 4598 million gallons, showing a total operating and maintenance cost of $2.14 per million gallons.

RÉSUMÉ

Sprinkling filters afford the cheapest available method for reducing the organic content of sewage to the point of stability or non-putrescibility. Where it is desired to secure a very high

grade of purification attention should be given either to the use of sprinkling filters of greater depth operated at lower rates than is the normal practice, or to the use of sand filters or hypochlorite treatment for the further purification of the effluent of sprinkling filters of ordinary rate and depth.

Sprinkling filters about 6 feet deep will regularly purify in the vicinity of two million gallons per acre daily and if the material contains few or no particles less than 1.0 inch in average diameter clogging is not likely to become a serious factor. In other words, such sprinkling beds seem to be permanent and without need of cleaning from top to bottom. Surface clogging may become a factor at times due to worms or vegetable growths which may be eliminated by applying hypochlorite of lime.

Fixed sprinkler nozzles for plants located in the northern states seem to afford the best means of application of sewage to the beds. The sewage so applied is preferably freed of settling solids and floating scum, so as to guard against clogging of nozzles and of filtering material. The unloading of suspended matters at intervals, due to the detachment of films surrounding the filtering material, is one of the most marked characteristics of sprinkling filters. In most cases final settling basins holding from one to three hours' flow are provided in order to separate this suspended matter from the effluent.

In practically every large purification project in America since 1905, where it has been necessary to oxidize the non-settling colloidal and dissolved organic matters, sprinkling filters have been recommended for adoption. For small installations contact filters have recently been restored in part to the favor in which they were formerly held. The reason of this is that contact filters filled from below are less likely to produce noticeable odors, and it may be cheaper to install them rather than to build an outfall sewer to deliver the sewage to a suitable isolated site for sprinkling filters. The odor attending the latter can readily be kept within reasonably small distances if the sewage is not allowed to become subject to the influence of anaerobic decomposition.

CHAPTER XXII

AERATION

Aeration has been studied in laboratories from time to time for many years in the hope of oxidizing the organic matter by the oxygen of the atmosphere. Mr. Dibden and Dr. Dupré studied this question at London in 1884 and came to the conclusion that aeration had but little effect upon the sewage and polluted waters which they investigated. This led Mr. Dibden to the conclusion that the chemical aspects of the sewage problem at London must be subordinated to biological considerations. He pursued the matter further and early in 1887 read before the Institution of Civil Engineers a classic paper which had much bearing historically upon the establishment of the biological treatment of sewage.

Messrs. Rafter and Baker on page 222 of their book on "Sewage Disposal" speak of the London work and of studies in America by Profs. Leeds, Drown and Mason, all of which were to the effect that organic matter is not readily oxidized by aeration. Even the polluted water of the Niagara river showed only a very trifling change after passing Niagara falls.

The reason why atmospheric oxygen does not attack organic matter, as readily as most laymen believe, is that it is in a molecular and not an atomic state. It combines with a vast amount of organic matter only when in a nascent or atomic condition. Even then many of the organic matters in sewage are so stable that there is but little action upon them.

The best proof that atmospheric oxygen does not combine directly with a substantial portion of the organic matter in fresh sewage is to be found in the records on pages 26 and 27 of Chapter I, and particularly in the data of Tables 24 and 25 of Chapter II. The latter show that quite a number of hours elapse before bacterial decomposition on an aerobic basis causes an exhaustion of the atmospheric oxygen dissolved in the water which constitutes the main bulk of the sewage.

Increase in Stability.—It is a fact that the application of atmospheric oxygen, to replenish that which is consumed by

bacterial action, will increase the stability of sewage and prolong the period of aerobic decomposition. Conversely, it defers the commencement of anaerobic decomposition in the body of sewage taken as a whole. Atmospheric oxygen is contained in water only to the limits of saturation as set forth in Table 41, page 219. If sewage could receive from time to time throughout its entire mass sufficient air to keep some oxygen present at all times and places, anaerobic decomposition would not set in and so-called putrefaction with its attendant bad odors would not exist.

Direct Oxidation.—While the organic matter in fresh sewage does not combine appreciably with the oxygen dissolved in the liquid portion of the sewage, yet, as bacterial decomposition proceeds, some decomposition products are formed of a sufficiently unstable character to combine directly with the molecular oxygen of the atmosphere. This is characteristic of stale sewage found in the outfalls of large sewerage systems and even in small ones where conditions of anaerobiosis are established. It is still more true of septicized sewage. Proof of this is found in the avidity with which septic effluents, particularly during the summer months, seize oxygen when aerated. While fresh sewages as applied to sprinkling filters retain 60 to 80 per cent. of the atmospheric oxygen needed for saturation at the given temperature, and will continue to show this oxygen in decreasing percentages for some hours; it was noted on page 467 that Mr. Barbour found at Saratoga that the aerated septic effluent was reduced from about 70 to 40 per cent. in dissolved oxygen content as the liquid flowed from the aerator to the sand filters. At Columbus there have been times during the summer months when aeration at the sprinkler nozzles left no oxygen in the septic effluent that was discernible in the samples as they reached the laboratory. During the colder seasons of the year they would remain well supplied with atmospheric oxygen for some hours. Corresponding observations are noted in Mr Wisner's 1911 report in the waters at the foot of the Chicago drainage canal, as stated on page 259. Reference is also made on page 33 to reports of Mr. Clark, who was one of the first to study this question of recording the quality of sewages by their avidity for consuming atmospheric oxygen. Efforts to take advantage of this direct oxidation have been made by Messrs. Lowcock, Ducat and Waring, but so far as we recall

none of these aerating arrangements have been of practical merit other than as an aid to biological treatments. The late Mr. Alsing, Consulting Engineer of the city of Glasgow, designed an elaborate brick structure covering an area of 5386 square yards with a view to purifying the effluent of the Glasgow chemical precipitation tanks. According to Messrs. McDonald and Taylor, this aeration project produced no discernible improvement in the effluent. Perhaps the latter statement would be more nearly correct if it were confined to direct oxidation, as it is quite probable that the stability of the effluent was increased if measured by the methods recently devised by Prof. Phelps and described on pages 39 to 43.

PROPOSED AERATION FOR NEW YORK SEWAGE

In February, 1911, Col. Black and Prof. Phelps submitted a final report on certain matters related to improved sewage disposal for the city of New York. Reference has already been made on page 360 of Chapter X, to the substance of this report, and on pages 39 to 43 of Chapter I an extended quotation is given of an important improvement in methods of measuring the stability of sewage. Following this quotation on page 43 of Chapter I, the report of Messrs. Black and Phelps proceeds to note the change in the putrescibility coefficient due to aeration. The percentage improvement during each of the six periods of tests that we have quoted are stated as 45, 136, 118, 65, 177 and 320, respectively. This improvement due to aeration is stated to have been measured by the concentration of sewage required to reduce the dissolved oxygen-content of the water 20 per cent. in six hours. This time interval was taken as it respresents a half tidal period. On page 77 of the report of Messrs. Black and Phelps, it is concluded that all of the data taken together plainly show that, during the hot weather months, the critical period in harbor conditions, the stability of a sewage as measured by its withdrawal of oxygen from the diluting waters, can be increased from two to threefold by the application of short period septic action, and by aerating in a deep tank; and that an air consumption of approximately 0.1 cubic foot per gallon will doubtless be sufficient under these conditions. They further add that this means that under any stated conditions of permissible pollution in the local harbor waters, the maximum

amount of sewage which can be disposed of in the harbor is increased two to threefold by this treatment.

Their report does not deal with the sludge question, as with a relatively small septic tank the problem is stated to be not greater than with any other processes and that the residual sludge will have to be dealt with by methods now in vogue, most likely by removal in scows.

The investment cost is estimated in this report as $2000 per million gallons of daily capacity and the cost for electric current alone at four cents per kilowatt hour is given as $2.00 per million gallons. The labor charges are not given, but are stated to be exceedingly low.

As to conditions under which the aeration process might be suitable and sufficient, it is stated that it would be applicable only where it would be necessary to use it during the summer season, perhaps for four months each year. It it not applicable for conditions where in the winter any purification is demanded. It is further pointed out that under some local conditions less perfect results than those obtained at the East New York sewage disposal works and the Boston testing station of the Massachusetts Institute of Technology might be ample. The report closes with the statement that the merits and possibilities of the process have been only barely indicated in the investigation described, and that a fruitful field has been opened for future investigations.

From the results tabulated in the report of Messrs. Black and Phelps and quoted by us in Table 21 of Chapter I, it is noted that the oxygen consumed in the crude sewage, aerated crude sewage and aerated septic sewage, are 75, 58 and 53 parts per million, respectively, for the months of April to August, inclusive. Whether this would hold true even to an approximate degree for other sewages is uncertain. Furthermore, this problem is aimed essentially at a set of local conditions where it is desired to preserve the stability of the sewage for a half tidal interval of six hours, at the end of which it appears to be assumed that the sewage would reach ample diluting water of the ocean.

We will not attempt to discuss in detail the general applicability of this process, especially for long inland streams receiving sewage at various points along their flow. Presumably the method was not developed for such conditions, as it would seem to require a repetition of the aerating process at intervals. The

latter step may be of much importance for some long outfall sewers. Taking the aerating method as a general proposition, it seems to us that the future will have to decide whether or not it is worthy of adoption under any circumstances. As applied to East New York conditions, where the sewage is discharged into the fairly shallow Jamaica bay, it would not protect shellfish from pollution. It might also encounter complications from sludge on the bottom of the bay, due to the precipitating action of salt water. It is difficult for us to conceive of its applicability for the sewage of Manhattan island, where the system of short sewers should deliver the sewage to the water front before there is much opportunity for deoxygenation of their contents.

CHAPTER XXIII

HYPOCHLORITE TREATMENT

This treatment relates essentially to the destruction of objectionable bacteria, particularly the germs of intestinal diseases, as found in sewages and sewage effluents. It is usually spoken of as a sterilization or disinfection process.

The addition of a hypochlorite serves in a measure to guard against bacterial decomposition of unstable sewages or sewage effluents. If liquids highly charged with organic matter are sterilized, they can be kept in a closed container for many days without anaerobic decomposition occurring. This method of guarding against anaerobic decomposition (or of the preservation) of organic matter is difficult to apply in practice. Theoretically a sterilized sewage or sewage effluent might flow in a stream for many hours without the development of bacteria to the extent of bringing about "putrefaction." The difficulty of applying this in practice is that many stream beds where this method might be helpful are now well supplied with sludge that is highly charged with bacteria. Furthermore, bacteria reach the watercourse through the washings of the soil following every rain. In fact, the waters of all surface streams are usually well supplied with bacteria.

Historical Development.—Since the middle of the last century oxidizing chemicals, including the hypochlorites, have been used from time to time for sewage treatment. For 25 years hypochlorite of lime, frequently spoken of as chloride of lime, has been known to be one of the most efficient sterilizing agents and indeed the cheapest chemical for destroying objectionable bacteria. In the early days of its use prior to the development of modern bacteriology it was applied with the apparent view of preserving the organic content of sewage, or as an oxidizing or deodorizing treatment. In 1884 and again in 1887 it was used by Mr. Dibden for the treatment of the foul waters of the lower Thames, before the present disposal works were completed. It was found to be necessary to apply the chloride of lime regularly in order to secure deodorization. Otherwise putrefaction was

simply delayed and anaerobic decomposition set in as soon as the needed bacteria were able to grow readily. Permanganate of soda was also applied as a deodorant. It was successful in that regard, but expensive, and in small quantities was not a germicide.

Following the outbreak of cholera in 1892 at Hamburg, renewed study was given to the use of hypochlorites as germicides. Complete or substantially complete sterilization was striven for and the cost of such treatment retarded the practical application of the method. It was largely due to the work of Dr. Rideal of London in 1905 that this method has recently been viewed in a different light. His work at Guilford showed that with smaller quantities of the chemical than had hitherto been considered practicable the vast majority of objectionable bacteria could be destroyed, although complete sterilization was not attained. This work was promptly confirmed at Boston by members of the staff of Prof. Sedgwick. The practical standing in America of this process is largely due to the work of Prof. Phelps at Boston, in conjunction with Mr. Carpenter; at Redbank, N. J., in conjunction with Mr. Daniels; and at Baltimore, Md., in conjunction with Mr. Whitman.

A well-prepared statement of this whole subject was made by Prof. Phelps in 1909. It was published by the United States Geological Survey as Water Supply Paper 229. Reference is made to that document for the details of the method, which may be briefly summarized here as follows:

Composition.—Commercial bleach contains hypochlorite of lime ($CaOCl_2$) and various impurities, of which the principal ones are unchlorinated quicklime and water.

Ordinarily there is about 75 or 80 per cent. of $CaOCl_2$ and say roughly 20 or 25 per cent. of impurities.

When hypochlorite of lime is dissolved in water is produces at once equivalent quantities of chloride of calcium ($CaCl_2$), which is inert, and of hypochlorite of calcium (CaO_2Cl_2). It is the chlorine ($Cl_2=71$) of the latter which measures, by the Penot method, the oxidizing strength of the product.

$$2CaOCl_2 = CaCl_2 + CaO_2Cl_2$$
$$2\times 127 = 111 + 143$$

$$\text{"Available chlorine"} = \frac{71}{143}\times\frac{254}{254+\text{Impurities}} = 36-37 \text{ per cent.} \pm$$

The commercial product loses strength through absorption of water and volatilization.

Reaction.—The hypochlorite of calcium, which does not exist as a separate solid compound, is decomposed by the carbonic acid in the presence of water.

$$CaO_2Cl_2 + CO_2 + H_2O = 2HOCl + CaCO_3$$

Hypochlorous acid (HOCl) is a weak non-poisonous acid, but a powerful oxidizing agent. When it comes in contact with a reducing agent such as the fairly unstable organic matters in sewage or sewage effluents, it is decomposed. Nascent or atomic oxygen is what really does the work as a germicide, deodorizer and oxidizer of organic matter. Hydrochloric acid is set free. It combines with carbonate of lime, forming calcium chloride. Sewages normally contain more than sufficient carbonic acid to bring about the reaction above stated. The hypochlorite will do its work in the absence of any acid, but somewhat more slowly. The term "available chlorine" does not mean that it is chlorine which does the work. The expression is a misnomer. It is simply a convenient expression now in general use for measuring the oxidizing strength of commercial hypochlorites in terms of chlorine. It is more appropriate to record the strength in terms of oxygen, or as Prof. Cornwall suggests, as "potential" oxygen. Available chlorine multiplied by 0.2257 gives "potential oxygen."

Required Doses.—According to the work of Prof. Phelps, crude sewages depending upon their strength require from 4 to 12 parts per million of available chlorine, septic effluents from 10 to 15 parts and sprinkling filter effluents from 3 to 4 parts. One part per million is equal to 8.34 pounds per million gallons. Where analyses are not regularly made of the strength of the bleach it is fair to assume at least 33 per cent. of available chlorine in the commercial product. This means that for one part per million of available chlorine there is required to be added about 25 pounds of the commercial bleach per million gallons. The required dose depends upon the amount of unstable organic matter present in the liquid to be treated. This explains why a septic effluent requires a larger dose than crude sewage. About 5 or 6 parts per million should suffice for a settled sewage that is fresh and well supplied with dissolved oxygen.

Efficiency.—The doses above stated should cause the removal of 95 to 99 per cent. of the bacteria present in the liquid undergoing treatment. The removal depends in part on the time of

contact, the temperature of the sewage and the number of spore-forming bacteria present. The latter fortunately do not include the germs of intestinal diseases. Solid particles of sewage are of course sterilized only upon the surface, and germs within the particles are not destroyed. This is another reason (besides economy) why it is best to work with settled sewage rather than crude sewage or the effluent of single-story septic tanks. The time of contact should be at least 15 minutes, and 30 minutes is somewhat preferable. If a longer period than this is available the doses may be reduced somewhat. The process is more effective in a short interval of time at summer than winter temperatures.

Cost.—The commercial hypochlorite of lime in large orders costs from $25.00 to $30.00 per ton, depending upon freight rates from the factory and the size of the order. For plants in regular service a single drum is naturally more expensive per pound than is a carload lot. The cost of new construction work depends upon existing arrangements. It may be but very little, if there is an outlet pipe of sufficient length through which the treated sewage may pass before it reaches its final disposal in the stream. Frequently ample tanks are available from present works. It can be readily seen that each problem requires special consideration for its own conditions. The same is true as regards attendants. Sometimes for large plants they require a special set of men for this purpose and in other instances one or two hours' work in the 24 is sufficient and can be provided by men who have other duties. If the treated liquid discharges into a large stream it is probably cheaper and better to apply a liberal amount of bleach rather than to try to adjust the dose very closely to the varying composition of the sewage at different hours. For a small stream, however, this is scarcely feasible, as an excess of this chemical is likely to be injurious to fish life.

Electrolytically Prepared Hypochlorites.—The electrolytic decomposition of sea water or solutions of common salt bring about the formation of hypochlorite of soda. This was tried some 20 years ago or more by Messrs. Webster, Woolf and Hermite. The Woolf process was applied in 1893 at Brewsters, N. Y., for treating the sewage of a small village situated on a tributary of Croton river, the main source of water supply of New York city. Various investigators have looked into this matter, but the relation of

the electrolytic treatment for the formation of hypochlorites is not sufficiently certain to recommend its regular use.

In connection with the treatment of public water supplies the use of hypochlorites has been the most widely followed in America. In 1908 this treatment was recommended by Messrs. Hering & Fuller for the impounded water supply of Jersey City at the Boonton reservoir, and by Mr. George A. Johnson for the effluent of the mechanical filter plant for treating the water of Bubbly creek, at the Chicago Union Stock Yards. The former plant was exhaustively studied and is outlined at length in papers by Messrs. Leal, Fuller and Johnson in the *Proceedings of the American Waterworks Association* for 1909, pages 100–147.

Water power at nominal cost may be secured for generating electricity from the discharge of the Boonton reservoir into the aqueduct leading to Jersey City. Even under these circumstances it was considered preferable by the Jersey City Water Supply Co., to use the commercial product rather than to manufacture hypochlorites electrolytically from salt solutions at the Boonton reservoir.

Sentimentally, electrolytically-prepared hypochlorites are doubtless somewhat preferable to hypochlorite of lime for the treatment of water supplies. Notwithstanding this fact, the author recently has recommended for sterilization of the Croton water supply in connection with the proposed new filter plant the use of the commercial salt, but provision will be made in the buildings at the filter plant for the installation of electrolytic equipment when that process becomes established on a more satisfactory basis.

One of the difficulties with the electrolytic treatment is that the electrical and chemical requirements of the process work at cross purposes. High electrical efficiency means a low yield of the desired chemical from the salt solution, and a high yield of hypochlorite from the latter means low electrical efficiency. There are several patented electrolytic cells upon the market, mostly in use in industrial establishments.

Prospective Use at Sewage Works.—This treatment has been recommended at a number of places where objectionable sewage bacteria are related to shellfish pollution. Mention may be made of the works at Providence, R. I.; Stratford, Conn.; New Brunswick and Riverton, N. J. At Baltimore Mr. Hendrick states that it will be used if found necessary or desirable to

supplement the purification obtained from sprinkling filters. As already stated, it was found cheaper to sterilize the effluent of the latter rather than to apply it to sand filters.

Away from the Atlantic seacoast the use of the process to protect the purity of inland streams has been rather scattered and related to small installations. Recently the State Health Department of Pennsylvania suggested to the city of Reading the desirability of sterilizing its sprinkling filter effluent with a view to further protection of the water supply of Philadelphia, which in part is taken from the Schuylkill river, some 50 miles below the city of Reading. It seems likely that it may come into favor, in connection with screens or sedimentation, to prevent local nuisances from floating and settling solids, for cases where there is ample water to dilute the non-settling and dissolved matters so that anaerobic decomposition will not result. Such treatment would probably be cheaper than filtration.

Hypochlorite treatment, as already stated, is of aid in the operation of filters for destroying various growths which tend to clog filter surfaces.

CHAPTER XXIV

OZONIZATION

Ozone is a modified form of oxygen which is a far more active and powerful oxidizing agent and germicide than is the ordinary molecular oxygen of the atmosphere. Ozone is produced by the silent discharge through air of an electric current under high potential. From time to time for many years it has been suggested as a purifying agent for polluted water supplies. This method has been installed at a number of places in Europe, at Lindsay, Ontario, at Ann Arbor, Mich., and to a limited extent for the water supplies of some of the suburbs of Baltimore, Md.

In 1907 the author had occasion to study this matter at some length in connection with the purification of the water supply of New York City. The results of tests were not satisfactory, owing both to the expense and irregularity of production of the ozone.

Unquestionably there have been substantial improvements made recently in the reliability and economy of the production of ozone. We shall not enter into this subject in detail. A description of the more important European devices is given in Chapter VIII of Messrs. Don and Chisholm's recent book on "Modern Methods of Water Purification."

American experiences up to 1910 are well reviewed in *Engineering News* of April 28, 1910. During that year the author had occasion to look into this matter in connection with the water purification works for the city of Montreal, P. Q. His advice was to continue the application of hypochlorite of lime rather than to attempt ozonization even where very cheap power will be available from a municipal hydro-electric plant adjoining the filter site. A similar recommendation was made by the author to the city of Niagara Falls, N. Y., where cheap power is also available.

Recently ozone has come to the attention of the author as a means of purifying sewage by the Meeker ozonizer which, with other arrangements, is owned by the American Sewage and Water Purification Co. of Newark, N. J. Mr. Arthur G. Fowler,

chemist of that company, has kindly furnished the author with memoranda indicating the progress made during the past 20 years in the number of grams of ozone manufactured per kilowatt-hour of electric current used.

TABLE 100.—PROGRESS MADE IN MANUFACTURE OF OZONE FROM 1890 TO 1911

Manufacturer	Date	Grams O_3 per kw.-hr.
Berthelot	1890	1
Tindal	1897	7
Schneller	1905	22
A. Otto	1908	40
Siemens	1908	74
Gerard	1909	85
Steynis	1910	200
Meeker	1911	215

Mr. A. C. Gregory, engineer of sewers of the city of Trenton, N. J., has called the attention of the author to a contract which is said to have been recently made by the American Sewage and Water Purification Co. with the city of Trenton, the principal features of which are as follows:

The contractor agrees to construct at his own expense the first installation or first unit of the plant which is to be operated so as to give satisfactory results to the State Board of Health and the Board of Commissioners of the city of Trenton. If the first unit does not give satisfactory results to these authorities, or either of them, as regards efficiency and economy, then the contract for the entire plant shall become nul and void and the contractor shall not be entitled to any claim for damages on account of such anullment or voidance.

The contract specifies clearly that screens, sedimentation tank, sludge digestion tank, sludge filter presses, with their various appurtenances shall be included with the ozonizing apparatus as a portion of the complete plant.

The details of the complete system upon which bids are invited are not specified, but it is set forth in the form of contract that within five days after the award of the contract a license or licenses shall be procured by the contractor and furnished to the city,

giving the latter full license power and authority to use any and all machinery, appliances and appurtenances that may be protected by letters patent, which shall be necessary to the construction of the works under this contract or any addition thereto or extension thereof, for and during the full term of said patent or patents or for any renewal or renewals thereof.

The main feature to be considered in these oxidizing methods is the relative efficiency and cost of ozone as distinguished from the nascent oxygen obtained through the use of hypochlorites. To convert ozone into available chlorine it is necessary to multiply the ozone figures by 1.447. This gives one of the data from which to figure the cost of production of ozone and of nascent oxygen which do equivalent amounts of work. The energy or efficiency of different oxidizing compounds is probably influenced somewhat by a variety of factors that are not well understood. Without attempting to discount the future in showing these relative costs, it seems to the author that it is quite important to compare the utility of ozone with that of hypochlorites in sewage treatment. Offhand it would seem as an engineering proposition that the outlook is not particularly encouraging, but it may be that the energy with which ozone combines with both living and dead organic matter may make the ozone process more practicable than now appears on the face of things.

CHAPTER XXV

INSTITUTIONAL AND RESIDENTIAL PLANTS

The disposal of sewage from institutions and country residences, removed from town sewerage systems, is quite an important part of sanitary engineering. While the plants are comparatively small, they are far more numerous than municipal works. They are of vital importance to those who have to dispose of sewage independently of town or city plants.

Mention will be made here briefly of several points which have come forcibly to the attention of the author. In the first place, it is to be pointed out that the irregularities in the rate of flow of sewage to these small plants are far more striking than is noted in a municipal sewerage system. This affects the hydraulics of the proposition in a number of ways. Dosing tanks, sprinkler nozzles and appliances of that sort, all have to be provided to take care of a maximum rate of flow, which in percentages above the average is far in excess of what is required in municipal works.

Speaking generally, broad irrigation, intermittent sand filters, contact filters and sprinkling filters, all may be used and have been used for small plants for institutions and in some instances for residences. Ordinarily the application of sewage by broad irrigation or intermittent sand filters is seldom adopted outside of the New England States, as the necessary porous material is not available. Where works of artificial construction are required, sand filters have rarely been built.

Sprinkling filters have not met great favor, as the aeration of the liquid from spray jets or other distributing arrangements causes noticeable odors unless the plant is unusually well isolated. The Montefiore Home, at Bedford Hills, N. Y., near Croton lake, built the first sprinkling filter to go into regular practical service in this country. It was designed by the author in 1907. As described in the *Engineering Record* of Feb. 15, 1908, the effluent from the filter passes through a small settling basin and thence through a series of trenches adapted from an earlier installation at the suggestion of Mr.

A. L. Webster. The sewage is received in a septic tank and discharged from a dosing compartment on to the sprinkling filters, which are covered by a wooden building. The quality of effluent has been satisfactory, and with few exceptions the plant has required comparatively little attention. For an institution as small as this, about 300 inhabitants, the rate of flow at times when the laundry tubs are being emptied reaches a high percentage above the average.

Sprinkling filters were also recommended by the author for the large State Insane Asylum at Kings Park, L. I., in 1908. The population was then about 4000, and has since been increased to about 6000. As frequently is the case, the appropriation for the project was made without regard to the local requirements, and a sprinkling filter was the only style of plant which could be built for the funds available. Very high rates of flow at certain hours of the day, with a characteristic laundry odor to the sewage, have been noticeable features of this plant.

Contact beds filled from below were designed by the author for the National Home for Disabled Volunteer Soldiers at Togus, Me. They are considered by the author to be a very satisfactory type of plant for institutions. It is the most reliable method now available for guarding against odors at disposal works which require to be built of artificial construction. If a third contact bed is employed and filled from the top, a very satisfactory effluent may be obtained, with a minimum burden for attendance and repairs. In fact, automatic dosing devices allow such arrangements to operate months at a time with merely a nominal attendance for a few minutes daily. Severe snows and zero weather do not interfere seriously.

Before the so-called modern biological filters were available it was frequently the custom to apply sewage to porous material beneath the surface through lines of open-jointed pipe. This method was spoken of as subsurface irrigation. Under favorable conditions it is probably the best arrangement to adopt for isolated residences and for very small institutions. The late Mr. Philbrick, the late Col. Waring, Col. George E. Olcott and a number of others were quite successful in installing this arrangement years ago. The success of the device depends largely upon keeping grease and suspended matters from entering the subsurface lines and clogging the openings in the distributing pipe. Preliminary sedimentation usually provides a reduction of

solid matters so far as feasible before the liquid passes into a chamber to be discharged by a siphon to the underground lines. By this arrangement the sewage is hidden from view, and even if once a year or so it is necessary to dig up and free the pipes from clogging, it is probably the best arrangement that is available in many of the Eastern states, where porous soil is at hand.

Where subsurface irrigation is not feasible on account of the imperviousness of the soil there have been a number of other arrangements suggested. Prof. A. Marston, of the Iowa State College, recently described the conclusions to which he has arrived as a result of various tests on small plants. He recommends the use of a cesspool overflowing into a two-story filter, the upper bed consisting of 4 inches of sand, through which the sewage drops to a lower bed of gravel 3 feet deep. Such a plant to serve the ordinary household may be arranged in a circular pit 12 feet in diameter, with a ventilator rising about 5 feet above the surface of the ground.

Mr. R. W. Pratt described in the *Bulletin of the Ohio State Board of Health* for July, 1911, disposal plants for isolated residences. He gives a comprehensive discussion of the principles involved in such plants and points out the differences between those and large works. In applying these principles he states that the outflowing sewage from the houses should be delivered into a settling basin of sufficient size and of suitable design to afford opportunity for the sedimentation of the settling solids and the rise of the grease. The capacity of the tanks is given as about one to two days' flow. The solid matters retained in the tank should be undisturbed so far as practicable by the influent and effluent connections. Residential sewage is so fresh and the suspended matters are so uncomminuted that there is much solid matter, particularly scum, which is formed in these tanks. Care should be taken to prevent its passage from the tanks so far as practicable. Now and then accumulations of solids within the tank must be cleaned out, probably not oftener than once a year. The tank should be ventilated through a soil pipe at the house or some other conveniently located building in a manner similar to the ventilation of modern sanitary sewer systems.

A dosing device is considered essential for the application of the tank effluent to the "absorption" system. The latter refers to either subsurface irrigation or artificially built sand beds.

In the former case agricultural drain tile or vitrified pipe are laid with open joints nearly level within 1 or 2 feet of the surface of the ground. The length should be determined by the porosity of the soil and should amount to 20 to 100 feet for each person connected with the sewer. It is found that in clayey soils it is necessary to underdrain the land to a depth of 3 to 4 feet. It is preferable to arrange the underground pipes in two or three groups or sections so that the flow may be changed from one set of pipes to another every week or so.

Where subsurface irrigation is not feasible Mr. Pratt speaks of sand filter beds, which, however, should be on a somewhat more liberal basis than for municipal plants. This is particularly due to the high rates of flow at certain times from the laundry and the fact that it is easier to operate a plant free of odor with a low rate than it is to give sufficient attention to prevent odors from plants operated at comparatively high rates.

Several small plants are described in the *Journal of the Association of Engineering Societies*, April, 1906, Vol. XXXVI, pages 131–54.

CHAPTER XXVI

COMPARATIVE SUMMARY

Sewage treatment works as outlined in Chapter XI are discussed in general terms in the résumés appearing at the close of Chapters XII to XXI, supplemented by the brief statements of the remaining chapters. Nevertheless it is thought that it may be helpful briefly to compare some of the general features of the methods herein described, as follows:

ABSENCE OF STANDARD METHOD

One of the most conspicuous facts to be borne in mind is that there is no standard method of procedure for the treatment of sewage, which can be uniformly applied to a large number of problems with a view to securing satisfactory hygienic results at least cost. Various partial methods, arrangements or devices are suitable in some combination or another for a large number of problems. But there is no cure-all or appliance which can be installed for all problems. Each set of local conditions should be carefully studied, in order to secure proper hygienic efficiency with due regard for economy of construction and operation, before new works are adopted, or extensions made to existing works.

GENERAL CLASSIFICATION

The methods of treating sewage may be briefly classified under headings as follows:

Well Established Methods.—Chemical precipitation, intermittent sand-filters, contact beds, sprinkling filters, settling tanks, septicization of sludge, hypochlorite treatment for sterilization, and fine screening may be considered the methods of sewage treatment that are reasonably well established as judged by the present status of the art of sewage disposal. The processes are named in approximately the order in which they have come to general recognition in America. Perhaps there is some room for discussion as to the order and even as to the inclusion of some of the methods in this list. It is believed, however, that this list

is in general harmony with work being done at present by the great majority of those who give this subject most attention. These methods will also appear under the following headings which are given to emphasize certain features of their development.

Recently Developed Methods.—While it is frequently said that there is nothing new in any line of sanitary engineering, it is to be pointed out here that the last half dozen years have seen great strides in advance in the applicability of sprinkling filters (in northern climates), sterilization or disinfection methods, utility of plain sedimentation, the practicability of septicization particularly in two-story tanks, and the benefits of fine screens. The efficiency and reliability of these devices is now quite well defined through plants in practice. Opinions on the several processes as a whole are quite well established, the differences relating to minor details.

Methods of Limited Applicability.—Chemical precipitation and broad irrigation which were the leading methods of a generation ago are now adopted but rarely for new works. In fact, existing plants using these methods are being abandoned and their applicability relates to quite unusual local conditions in America. Both of these methods have a much higher standing in Europe, particularly the method of chemical precipitation in England. Intermittent sand filters are being installed in New England and a few other localities where suitable areas of porous soil are available. Taking America as a whole, intermittent sand filters are applicable only to a limited section. Where this method requires the construction of artificial beds, other methods have been adopted in the interest of economy.

Waning Methods.—Chemical precipitation and broad irrigation are unquestionably upon the wane in America. This is scarcely true of intermittent sand filters, as they have increased in number in districts where geological conditions make them naturally suitable. Elsewhere they have never become a well-recognized method.

Unestablished Methods.—The electrolytic treatment, strainers, slate beds, colloidors, aeration and ozonization, have not become established on a recognized basis in America.

Practice has not become well defined as to how far it is wise to use screens in the preliminary treatment of sewage which later is to pass through sedimentation basins, or as regards

the need and relative advantages of fine screens, strainers or mechanical filters for freeing settled sewage of suspended matters.

The benefits of two-story tanks in which sedimentation occurs in the upper compartment and sludge digestion in the lower compartment are not conceded by all workers. It is the judgment of the author, however, that a careful study of all the evidence leads to no uncertainty as to the great advantages of this arrangement. Greater experience will doubtless result in improvements of certain details.

Practice varies somewhat as to the use of settling basins and sand filters for the treatment of the effluent coarse-grained filters. Different local conditions call for different designs and variations in procedure will no doubt continue for some time.

EFFICIENCY

In the autumn of 1906 the author prepared in collaboration with Mr. Rudolph Hering a comparative statement of the purification of raw sewage by different methods for a report to the International Waterways Commission, as shown in Table 101.

TABLE 101

Method	Percentage purification		
	Suspended matter	Organic matter	Bacteria
Fine screens (30-mesh or finer)	15	10	15
Sedimentation	65	30	65
Septic treatment	65	30	65
Chemical precipitation	85	50	85
Contact filters[1]	85–90	65–70	80–85
Sprinkling filters[1]	85–90	65–70	90–95
Intermittent sand filters[1]	95–99	90–98	98–99

[1] The figures for the last three forms of treatment are on the assumption that the sewage is given some form of preparatory treatment before it is applied to the filters, and that with the sprinkling filters the effluent is allowed to settle.

The above figures are still a fair approximation to results which may be expected ordinarily in practice. While they suffice in the opinion of the author as a rough indication of what may be expected, they undoubtedly could be amplified to show

the influence of different conditions, particularly of the composition of the sewage undergoing treatment. We will not discuss further this matter which is taken up in the different chapters.

The first four methods are clarifying arrangements and do not give a non-putrescible, stable effluent, as is obtained with the three methods of filtration. Bacterial results vary widely.

COMPARATIVE COST

In the 1906 Report to the International Waterways Commission, Mr. Hering and the author compared the estimated cost of installing and operating intermittent sand filters, contact filters and sprinkling filters, respectively, for the treatment of 180 million gallons of sewage of the Calumet district of Chicago, with an ultimate population of 1,200,000, including intercepting sewers, pumping stations and single-story septic tanks, as follows:

	Investment cost	Annual operating cost
Intermittent sand filters (1200 acres).	$11,063,000	$866,000
Contact filters (300 acres).....	11,787,500	551,000
Sprinkling filters (80 acres).....	9,257,500	419,000

Of the investment costs above given about $3,800,000 was required for intercepting sewers and pumping stations with the contact filters and sprinkling filters, while about $5,600,000 was so required for sand filters with their larger area.

Of the above operating costs about $200,000 was required for pumping in the case of the contact and sprinkling filters and $300,000 for sand filters.

It was assumed in the above estimates that the contact and sprinkling filters would require the material to be removed and cleaned from time to time, about once in 10 years on an average. Later information would now reduce the operating expenses for such coarse-grain filters as there is no probability of suitably built beds requiring cleaning from top to bottom. Smaller installations, however, would cause the filter costs to be somewhat larger than for a plant such as estimated upon above.

It is not very satisfactory to attempt to record general costs of sewage treatment, as will be appreciated from a study of the varying data in this book. However, for general reference the author has found that some aid is obtained from a comparative summary, as follows:

TABLE 102.—APPROXIMATE AREAS, COSTS AND CAPACITIES OF WORKS FOR TREATING THE SEWAGE OF 10,000 PEOPLE ON THE BASIS OF 100 GALLONS PER CAPITA (SEPARATE SYSTEM).

	Area	Capacity (gallons)	Cost
Grit chamber[1]	150 sq. ft.	750	$200–$500
Preliminary fine screens[2] (36 meshes to lineal inch)	400 sq. ft.		4,000–5,000
Preliminary two-story settling tanks:			
Upper compartment	3,000 sq. ft.	150,000	8,000–15,000
Lower compartment		100,000	
Sludge drying beds (or filters) 1 ft. deep	3,500 sq. ft.		600– 1,000
Intermediate fine screens	400 sq. ft.		4,000– 5,000
Roughing filters	350 sq. ft.		2,000– 3,000
Intermittent sand filters	17 acres		8,500–85,000
Contact filters (5 ft. in depth)	1.7 acres		22,500–60,000
Sprinkling filters (6 ft. in depth)	0.5 acre		15,000–25,000
Final settling tanks	1,000–2,000 sq. ft.	75,000–100,000	5,000–10,000
Hypochlorite treatment	400 sq. ft.		1,000– 3,000
Final sand filters	2 acres		1,000–12,000

[1] Not needed for separate sewers.

[2] Fine mechanical screens not now made smaller than for 5 million gallons.

Filter areas are net effective surface; all others are gross building areas.

The annual cost, independent of supervision and pumping, of operating works to treat the sewage of 10,000 people, exclusive of hypochlorite treatment or final sand filters, would range from about $600, with automatically-controlled contact beds or sprinkling filters to sums of from about $1500 to $2500 for intermittent sand filters.

Laboratory supervision usually costs from $1000 to $1500 per annum for fairly small plants. There is no direct relation between the cost of supervision and the size of plant within certain limits. In fact, the size of plant influences rather irregularly the cost of supervision and makes it difficult to deal satisfactorily with operating costs when expressed on an annual per capita basis.

NEED FOR GOOD MANAGEMENT

Well-planned and well-built sewage treatment works sometimes give unsatisfactory results through mismanagement or neglect. No engineer can design works which will uniformly give satisfactory results unless they receive some attention from time to time. This is true even of automatic devices which have reached a high state of development and lessen the burden of manual labor quite materially as compared with the practice of a few years ago.

Worcester, Brockton, Providence, Plainfield, Reading, Columbus, Baltimore, and some other places, have established laboratories and provide proper attendance for the intelligent direction of the disposal of the local sewage. Even for small plants it has been the custom of the author to provide small laboratories where simple tests for putrescibility may be made and careful records obtained as to what the different parts of the disposal works are doing. Even for small towns it is the belief of the author that this is well worth while. If increased faithfulness is not given to the proper operation of sewage disposal works, it is only a question of time when steps should and will be taken by State authorities in the more thickly populated sections of the country to make compulsory the proper management of sewage disposal works.

INDEX

PAGE

Abbott, Prof. A. C 134
Accrington, England, sprinkling filters 691
Adams, G. O 32
Adeney, Dr. W. E 353– 54
Aeration of sewage 39, 91, 228, 286, 362, 721– 25
  direct oxidation 722– 23
  in contact filters 679
  increase in stability 721– 22
  in roughing filters 578
    sand filters 628– 38
    sprinkling filters 691, 700, 707
  proposed for New York City 723– 25
  with septic process 467, 499
Akron, Ohio, sewage testing station 189– 90
Albany, N. Y., death rates 102
Allardice, E. R. B 648
Allen, C. A 537
Allen, K 356, 395, 406, 449, 459, 470, 514, 516–17, 521
Alsing, G. V 723
Altona, Germany, cholera epidemic 101
Alvord, J. W 314, 492–93, 499, 502, 658, 668
American Sewage & Water Purification Co 732– 33
Ammonia, *see* Sewage composition.
Amyot, Dr. J. A 142
Analyses, *see* Sewage composition; various devices; cities.
Andover, Mass., sand filtration 619–21, 663
  sewage analyses 7
  sprinkling filters 710
Ann Arbor, Mich., ozonization of water 732
Annes, Prof 146
Ansonia Manufacturing Co 658, 684– 85
Aquatic growths in dilution methods 210, 222, 227, 231, 250, 261–75, 281, 296, 337
Artingstall, S. G 224
Altanta, Ga., Imhoff tanks 507, 529
  roughing filters 583
  screen 387
  sludge-drying bed 516
  sprinkling filters 693, 706, 708– 09
Atlantic City, N. J., infected oysters 134– 35
  screens 380
  sprinkling filters 691, 703
  strainers 578
Atmospheric oxygen, *see* Dissolved oxygen.
Augusta, Me., sewage farming 596
Automatic dosing devices 654–61, 684–87, 710– 18
Ayers 144

Bacteria, aerobes, facultative and obligative 51
  antagonism among 60
  B. coli and B. typhosus, vitality of 146
  B. putrificus 55

PAGE
(Bacteria,) B. typhosus in oysters and water ... 139–46
longevity of ... 120–23
resistance to heat ... 146
vitality of ... 146
Beggiatoa ... 78
classification of ... 51
conditions controlling growth of ... 60–61
dissemination of in air ... 702
effect of upon organic matter ... 61
enzymes ... 59–60, 482
fermentation and putrefaction ... 52
importance of ... 2
infectious, in streams ... 209
in oysters and shellfish ... 143–44
sewage, number, kinds and weight of ... 44–38
unpolluted sea water ... 141–43
objectionable, removal of from streams ... 209
parasites ... 51
relation to kind of food ... 52
offensive odors ... 86–99
oxygen ... 51
shellfish ... 125–74
sulphur compounds ... 77–80
water supplies ... 100–24
removal of from streams ... 207, 211
See also various devices and processes.
saprophytes ... 51
species of at Columbus, Ohio ... 47
Spirillus desulfuricans ... 76
symbiosis among ... 60
Thiothrix ... 78
Baffles for sedimentation tanks ... 426
Bailey-Denton, J ... 616
Baker, M. N ... 176, 223, 262, 403, 433, 469, 502, 535, 537, 577–78, 595–97, 602–03
Baltimore, Md., hypochlorite treatment of sewage ... 730–31
ozonization of water ... 732
sand filtration ... 625–27
septic tanks ... 476–79
sewage disposal methods ... 179, 331–32, 476–79, 502, 625–27, 697, 708, 710, 730–31
testing station ... 669
sprinkling filters ... 697, 708, 710
Barbour, F. A ... 21, 436, 438–39, 451, 467, 654, 660–61, 668, 685, 722
Bass, Prof. F. H ... 456
Bassett, C. P ... 142
Batavia, N. Y., Imhoff tank ... 507, 509, 511
screens ... 384
sprinkling filters ... 693, 706, 717–18
Baumeister, Prof. R ... 5
Bayonne, N. J., death rates ... 112
Beard, E. H ... 693
Beardsley, F. S ... 160
Bechmann, M ... 604–05
Benzenberg, G. H ... 308, 311–12, 314
Berlin, Germany, sewage farming ... 610–13
tests ... 198
Berthelot ozone process ... 733
Binghamton, N. Y., death rates ... 102
Binnie, Sir A ... 668
Biological methods ... 615–17, 641, 721
Birge, Prof. E. A ... 280–304, 368, 374

PAGE
Birmingham, England, roughing filters 580, 699
sedimentation tanks 439
sewage analyses 9, 12, 22
sprinkling filters 580, 699
Black, Col. W. M 39–44, 91, 206, 217, 343, 360–64, 367, 723– 25
Blair 31
Blunk 517
Bolling, G. E 644–45, 647
Boonton, N. J., hypochlorite sterilization of water 730
Bordentown, N. J., contact filters 686
sand filtration 618
Boston, Mass., foiolytic tank 524– 26
grit chamber 402– 03
odor question 526
screens 380
sewage analyses 7, 8, 10, 22, 31, 42
disposal in harbor 320– 30
Boyce, Prof. R 77, 143, 145– 47
Bradford, England, sewage analyses 12, 22, 25
Bredtschneider, A 448, 585
Bridgewater, England, cholera epidemic 131
Briggs, B. E 312
Brighton, England, infected oysters 136
Britton, Dr 131
Broadbent, Sir W 134
Broad irrigation 595–614
analytical results 610
capacity 603– 04
extent of use 596– 99
financial aspects 600– 03
hygienic aspects 599–600
irrigation and manurial value 601– 03
odors 597–601
present status 613– 14
Brockton, Mass., sand filtration 644– 48
screens 380, 392
sewage analyses 7, 22, 619–20
Brooks, Prof 138
Brooks, F 577
Brown, W. M 342
Buchanan, Prof. R. E 76
Buffalo, N. Y., lake pollution at 305
Bull, W. B 574– 75
Bulstrode, Dr. H. T 133, 148

Cadaverin 55
Calmette, Prof. A 198, 613
Cameron, D 468, 491, 528
Cameron Septic Tank Co 526–32, 684– 85
Cameron, Sir C 132
Canton, Ohio, chemical precipitation 539
Carbon dioxide in filters 708
lakes 282, 290– 92
septic tank gases 483– 85
sewage 83, 92– 95
monoxide in lakes 294
sewage 83
Carpenter, W. T 727
Cassel, Germany, sewage tests 199
Cesspools 737
Chambersburg, Pa., Imhoff tank 507

PAGE
Chantemesse, Dr. A. 134
Charles river basin, sewage pollution in 7, 332–39
Chase, E. S. 26, 391, 419–20, 443, 454, 463, 695, 712, 716
Chatauqua, N. Y., chemical precipitation 539
Chatham-Madison, N. J., contact filters 676
Imhoff tank 507
sand filtration 618, 665
Chemical precipitation 376, 535–49
efficiency and cost 542–45
odors 543
present status 547–49
principles of process 539–42
projects 535–39
sludge disposal 546–47
Chesbrough, E. S. 223, 320
Chicago, Ill., Drainage and Water Supply Commission 224–30
canal litigation 246–53, 258–61
Sanitary District 437–38
Imhoff tank 507
testing station 8, 39, 43, 75, 669
sewage analyses 10, 13–14, 22
disposal by dilution 214–15
sludge disposal 455
street washings 13
trade wastes 13–14
Chiles & Whitman 712
Chisholm, J. 732
Chloride of lime, *see* Hypochlorite treatment.
Chlorine, *see* Sewage composition.
Choate, C. F., Jr. 176
Cholera at Altona, Germany 101
Bridgewater, England 131
Hamburg, Germany 100–101
Taunton, England 131
Wandsbeck, Germany 100
Cincinnati, Ohio, sulphide formation 73–74
typhoid fever death rates 102
vital statistics 113–15

Clams, *see* Shellfish.
Clapp, O. F. 537, 544, 548–49
Clark, H. W. 21–25, 31–33, 39, 68, 71, 74, 143, 146, 151, 333, 459, 467, 475, 481–82, 484, 500, 505, 539, 580, 584, 592, 621–22, 628–29, 635, 643, 653, 675, 684, 694, 703, 722
Cleveland, Ohio, lake pollution at 308–11
Clinton, Mass., sand filtration 648–49
sewage analyses 619–20
Collins, A. E. 505, 591
Colloidors 590–92
Cologne, Germany, sewage disposal methods 177–78
Columbus, Ohio, coke strainers 74, 579–80
contact filters 671
death rates 102
grit chambers 397–400
Imhoff tank 507
screens 380
sedimentation 393–94, 413–19, 430, 448
septic tanks 467–69, 492, 495, 497–500
sewage analyses 9, 10, 22, 26, 74–75
bacteria, kinds of 47
composition, variations in 17–20

PAGE
(Columbu, Ohio, sewage) disposal methods ... 178–79, 205
testing station ... 8, 33, 74, 466–69, 692
sludge disposal ... 453– 54
sprinkling filters ... 692–93, 696–97, 703–05, 708, 711–12, 719
street washings ... 13
Concord, Mass., sewage analyses ... 619– 20
Coney Island, N. Y., chemical precipitation ... 539
sludge incineration ... 459
Connecticut State Board of Health ... 654
Conn, Prof. H. W ... 132
Contact filters ... 667– 89
advantages and disadavantages ... 668– 69
analytical results ... 670– 74
automatic dosing devices ... 684– 87
capacity ... 675– 76
clogging ... 682– 83
construction features ... 680– 81
cost of construction and maintenance ... 687– 88
efficiency ... 669– 75
historical development and nomenclature ... 667– 69
material, character of ... 678– 80
depth of ... 680
kind of ... 679
size of ... 679
odors ... 687
operation features, contact period ... 681
filling from below ... 681– 82
rate of draining and filling ... 681
ripening ... 682
permanency—clogging ... 682– 83
principles of process ... 677– 78
relation to preliminary and final treatment ... 676– 77
worms and flies ... 684
temperature conditions ... 683– 84
Copperas in chemical precipitation ... 541– 44
Copper sulphate ... 643
Corbett, J ... 580, 691
Cornwall, Prof. H. B ... 728
Craighill, W. P ... 331
Crimp, S ... 550–668
Croes, J. J. R ... 342
Currents, relation to dispersion ... 201, 258, 278, 318
Currier, Dr ... 262

Daniels, F. E ... 727
Davis, J. P ... 312, 330, 536
Death rates, general ... 104– 14
typhoid fever ... 102– 14
variations in ... 111– 14
See also various cities.
Decomposition ... 50–85
conditions controlling ... 65
processes ... 58–59
products ... 81–84
Prof. Drown's views on ... 64–65
Nichols' views on ... 62–64
See also Sewage, decomposition of.
de Giaxa, Prof ... 132
Denitrification ... 71–72
Dereham, England, slate beds ... 583
Desulphurization ... 72–77

PAGE
Devizes, England, slate beds 580
Diarrhea epidemics 114, 118– 23
Dibden, W. J 583–84, 668, 721, 726
Dilution in inland streams 201– 76
American investigations 223– 75
analyses 232–34, 242–43, 247–48, 256– 61
aquatic growths 222
atmospheric oxygen in water 218– 19
caution necessary 222– 23
corrective measures 213– 14
degree of 214–16, 224–25, 239
dispersion 202, 216– 17
extent of use 204– 07
flora and fauna, significance of 261– 74
freedom from nuisance 201– 03
historical development 203– 04
initial oxygen 219– 20
processes involved 203
reaeration 220
residual oxygen 217
seasonal effects 220– 21
time factor 222
large lakes 277–317
dissimilarity to rivers 278– 80
effect of thermal stratification 279– 81
physics, chemistry and biology of 280–304
practical accomplishments 304– 17
similarity to rivers 277– 78
oceans and tidal estuaries 318– 72
action of tides and currents 318– 19
American experiences 320– 72
Baltimore disposal projects 331– 32
Charles river basin 332– 39
first sterilization plant at Red Bank, N. J 330– 31
general principles of diffusion 366– 68
Gowanus canal flushing project 368
Los Angeles project 370– 72
Metropolitan Sewerage Commission 352– 60
New Bedford disposal project 369– 70
New York bay and harbor pollution 339–40, 351– 52
Passaic valley project 349– 50
Providence harbor experiences 330
reaeration 364– 66
report of Col. Black and Prof. Phelps 360– 63
sewage disposal in Boston harbor 320– 30
standard of 70 per cent. oxygen 364
statement of special factors involved 318– 20
streaming effect 366
Dispersion of sewage in streams 202, 216– 17
sludge in water 453– 54
Dissolved oxygen in dilution methods 202–03, 352
See also Oxygen.
Don, J 732
Dortmund septic tanks 475
Drown, Prof. T. M 62, 64–65, 68, 188, 220
Dublin, Ireland, oyster infection 132
Ducat, Col 722
Dunbar, Dr. W. P 81, 198–99, 487, 585, 614, 677, 683, 711
Dunkirk, England, gastro-enteritis outbreak 131
Dupré, Dr 228, 721
Durand-Claye, A 595, 605

PAGE
East Cleveland, Ohio, sprinkling filters ... 692
East Orange, N. J., chemical precipitation ... 539
sprinkling filters ... 697
Eddy, H. P. ... 8, 20–21, 68, 213, 314, 369, 400, 436, 448, 450–51, 467, 480, 483, 523, 535, 544–46, 628, 650–53, 665, 697, 710
Edholm, C. L. ... 556
Elberfeld, Germany, sludge disposal ... 455–56, 459
Electrolysis, general description ... 558–61
See also Electrolytic treatment.
Electrolytic treatment of sewage ... 550–76
cause of passivity, initial and acquired ... 565–67
chloride process of W. B. Bull ... 574–75
electricity in direct oxidation processes ... 575
form in which iron leaves electrodes ... 567
fundamental laws and principles ... 561–65
general description of electrolysis ... 558–61
influence of oxygen and hydrogen ... 567–69
the solubility of initial iron compounds ... 569
differences in potential current ... 569
current density ... 569–70
reversing current ... 570
iron electrode conclusions ... 572–73
Louisville (Ky.) experiences ... 573–75
modifications in apparatus ... 574
Oklahoma City (Okla.) plant ... 556
percentage of metal wasted ... 571–72
electric power wasted ... 572
resistance of films of iron oxide ... 572
rusting of idle submerged electrodes ... 571
Santa Monica (Calif.) plant ... 553–56
status of decomposition of metal plates ... 557–58
Webster process ... 550–53
El Paso, Texas, sewage farming ... 600
Elsner, Dr. F. ... 406, 448, 452
Emmich, Dr. ... 228
Emscher sewerage district, Germany ... 25, 436–37, 505–24
sewage tests ... 199
tanks, *see* Imhoff tanks.
English data on sewage constituents ... 5
English origin of contact filters ... 668
intermittent sand filters ... 616
septic tanks ... 468
sprinkling filters ... 691
Enzymes ... 59–60, 482
Erie, Pa., lake pollution at ... 311–12
Evans, Prof. P. F. ... 367
Exeter, England, septic tank ... 469
Experiments in sewage disposal ... 187–200

Facilol as a deodorant ... 452
Fales, A. L. ... 400, 448, 451, 467, 538, 628
Faraday's law ... 561–62
Farley & Robinson ... 710
Fats, grease removal apparatus ... 405–06
in sewage ... 6, 7, 10, 13, 18, 25–26
removal of by sedimentation ... 421
Fermentation, definition of ... 52–53
distinguished from putrefaction ... 52–58
in alimentary canal ... 58
products ... 52–54
Fiegl, Dr. ... 482

PAGE
Field ... 141, 145
Field, Dr. G. W ... 263, 333
Filtration, contact filters ... 667–89
definition of ... 376
intermittent sand ... 615–66
mechanical ... 392–93
roughing ... 577–94
sprinkling ... 690–720
Fisher, E. A ... 311
Fischer, Prof ... 142
Fitzgerald, D ... 308
Fitzmaurice, Sir M ... 543
Flad, H ... 312
Flies and worms in sprinkling filters ... 701
relation to broad irrigation ... 600
Floating matter in streams ... 201–03, 210–11
Flora and fauna, significance of in streams ... 261–74
Flushing of sewers ... 90
Folsom, Dr. C. F ... 223, 320
Forbes, Prof. S. A ... 263
Forest Park, Md., sludge digestion tank ... 456
Fowler, A. G ... 732–33
Framingham, Mass., sand filtration ... 649–50
sewage analyses ... 6, 11, 22, 29
Frankfort, Germany, screens ... 385–86
sewage tests ... 199
sludge disposal ... 452, 459–60
Frankland, Sir E ... 72, 459–60
Freeman, Dr. A. W ... 169
Freeman, J. R ... 263, 333
Fresno, Calif., sewage farming ... 598–99
Frost, E. C ... 649–50
Fteley, A ... 342
Fuller, Prof. C. A ... 143, 168

Gage, S. DeM ... 143, 146, 169, 459, 481–82, 484, 500, 539, 580, 623–29, 635, 643, 675, 684, 694, 703
Gardner, Mass., coke strainers ... 578
sand filtration ... 663
sewage analyses ... 6, 10, 11, 16, 22, 29, 619–21
Gases from sewage decomposition ... 82–84, 92–95, 479–80, 483–84
Gastro-enteritis epidemics ... 117–18, 131
Gault, M. G ... 401, 545, 653
Gavett, A. J ... 668, 671, 688
Gennevilliers, France, sewage tests ... 197–98, 595
Gerard ozone process ... 733
Gill, Prof ... 483
Gloversville, N. Y., sand filtration ... 665
sedimentation tanks ... 436
sewage analyses ... 10, 22, 69
data, 1909 ... 8
testing station ... 8, 68, 669, 692
sludge bed ... 451
characteristics ... 445
sprinkling filters ... 693, 697, 703, 710
trade wastes ... 20–21
Goodell, E. B ... 183
Goodell, J. M ... 5
Goodnough, X. H ... 7, 151, 188, 241, 245, 253, 311, 333
Gowanus flushing tunnel ... 368
Gray, S. M ... 205, 307, 330, 331–32, 475, 536, 625

PAGE
Greeley, Colo., sewage farming ... 598
Gregory, A. C ... 733
Gregory, J. H ... 398, 431, 498, 509, 525–26, 693, 696, 703, 707, 712, 719
Griggs, J ... 398, 668, 693
Grit chambers ... 396–404
analyses ... 400
velocities ... 401
Guion, Dr ... 135
Güth, Dr ... 482

Hackensack, N. J., death rates ... 112
Hamburg, Germany, cholera epidemic ... 100– 01
sewage tests ... 198
Hamer, Dr ... 146
Hamlin, H ... 76
Hammond, C. A ... 715
Hampton doctrine ... 584– 90
England, septic tanks ... 503– 04
septic tanks, odor question ... 504
See also Septic tanks.
Hanover, Germany, sludge drying machine ... 460
Hansell, W. H., Jr ... 516, 707
Harburg, Germany, sludge drying machine ... 460
Harding, J. C ... 120
Harrison, E. W ... 263, 342, 350
Harrison, Pres. B ... 205
Hawgood, H ... 554
Hawk, P. B ... 45
Hazen, A ... 21, 62, 107, 213, 238–40, 311, 343, 406–13, 423, 426, 428, 433, 438, 502, 539, 630
Hazen theorem, the ... 107– 09
Hempstead, N. Y., sand filtration ... 655– 56
Hendrick, C. W ... 332, 390, 456, 502, 707, 730
Herbert, H. M ... 152
Herdmann, Prof. W ... 143, 145– 47
Hering & Fuller ... 252– 53, 312, 331, 342, 380, 388, 434, 496, 581, 661, 693, 708, 730

Hering, Prof. C ... 367
Hering, R ... 77, 88, 205, 224–30, 252–53, 307–08, 311–12, 330–32, 339, 342, 380, 387–88, 422, 434, 456, 474–75, 496, 505, 536, 581, 625, 661, 691, 693, 708, 730, 741– 42
See also Hering & Fuller.
Hermite electrolytic process ... 729
Herter, Prof. C. A ... 44–45, 52, 59
Hewlett, R. T ... 143
High Wycombe, England, slate beds ... 584
Hill, C. D ... 90, 146
Hill, J. E ... 498
Hinckley, H. V ... 556
Hoboken, N. J., death rates ... 102, 112
Hoffman, Dr ... 3
Holmes, J ... 251
Homewood, N. Y., sprinkling filters ... 692
Hommon, H. B ... 190
Hoopes, C ... 707
Hoover, C. B ... 39, 421, 454, 696–97, 712
Hopedale, Mass., sewage analyses ... 619– 20
Hoppe-Seyler ... 77
Horton, T ... 311
House connections ... 89
Houston, Dr. A. C ... 142–43, 146
Hoxie, G. L ... 598
Huddersfield, England, sewage analyses ... 12, 22

PAGE
Hudson, Mass., trade wastes....21, 25, 654
Humification of organic matter.... 81
Hydrogen as a reducing agent.... 88
in lakes.... 294
sewage....84, 92–95
phosphide (phosphine).... 84, 95
relation to electrolysis.... 568–69
sulphide, control of.... 95–98
formation from organic matter by numerous kinds of bacteria....77–80, 95–97
from Boston biolytic tank.... 526
Imhoff tanks.... 523
septic tanks.... 484–86
injury to masonry.... 75–77
in lakes.... 294
sewage....77–80, 92–98
physical characteristics.... 91–95
precipitation of.... 97
See also Sulphur.
Hypochlorite sterilization....178, 213, 330–32, 370, 376–77, 708, 726–31
treatment.... 726–31
chloride of lime.... 726–31
composition and reaction.... 73
efficiency and cost.... 728–29
electrolytic.... 729–30
historical development.... 726–27
prospective use at sewage works.... 730–31
required doses.... 728

Imhoff, Dr. K....25, 414, 505–24, 531
septic tanks....199, 331, 425–26, 436–37, 470, 475, 505–24
constructional features.... 508–17
extent of use.... 506–07
odor question.... 522–24
operating program.... 517–21
results of operation.... 521–22
sludge compartment computation.... 514
Indol....55, 84, 92
Institutional and residential sewage disposal methods.... 735–38
Intermittent sand filters.... 615–66
analyses....619–20, 626, 634–39
as final treatment.... 664–65
biological construction....615–17, 641
capacity.... 620–24
cost of construction and operation.... 662–64
efficiency.... 618–20
extent of use.... 618
influence of time.... 630
material, air and water capacities.... 631
character of.... 630–36
clogging features....627–28, 641–43
depth of.... 635–36
kinds of.... 633–35
limitations in dosing.... 632–33
mechanical analyses.... 630–31
methods of distribution.... 654–61
nomenclature and historical development.... 615–17
odors.... 661–62
relation to nitrification.... 637–41
oxygen.... 628–30
preliminary treatment.... 624–28
trade wastes.... 653–54

PAGE
Iron, action of electrolysis on 567– 69
Irrigation, broad 595–614
sub-surface 736– 38
Isle of Man, infected oysters 131
Ithaca, N. Y., lake pollution at 316

Jackson, D. D. 357
Jackson, W. W 499, 696, 719
Jacobsen, C. E. A. 342
James, T. H. 555
Jersey City, N. J., typhoid fever death rates 101
Johnson City, Tenn., septic tank litigation 529
Johnson, G. A. .8, 9, 17, 19, 26, 46, 74, 142, 397, 414, 453, 466, 478–80, 492, 579, 628, 671, 730
Johnston, J. H. 585
Jordan, Prof. E. O. 72, 116, 122, 246, 250, 617
Juday, Prof. C. 280–304, 368

Kastle, Dr. J. H. 103
Kelsey, L. C. 598
Kendall, Dr. A. I. 52, 59, 82
Kerr, J. E. 45
Kiersted, W. 423
Kimberley, A. E. 22, 401, 403, 423, 427, 430, 448, 489, 491, 493–95, 499, 623
Kings Park, N. Y., sewage disposal plant 434–35, 450, 457–59, 502, 706, 713, 736
Kinnebuehler, K. 433
Kinnicutt, Prof. L. P. 9, 31, 220, 475, 480, 483
Klein, E. 141, 143, 145
Knowlton, W. T. 372, 555, 597
Knoxville, Iowa, septic tank litigation 528– 29
Kremer grease removal apparatus 405– 06
Kubel 31
Kuichling, E. 211, 264–74, 311, 386, 402– 03

Lafar, Prof. F. 76–77, 79, 97
Lagooning of sludge 454– 56
Lake Erie, sewage pollution of 306
Lake Forest, Ill., sand filtration 658– 60
Lakes, physics, chemistry and biology of 280–304
Landis, Dr. J. H. 115
Lane, M. 320
Lanphear, R. S. 26, 382, 421, 487, 490, 496, 673
Latzer, L. L. 45
Lawrence, L. I., typhoid fever epidemic 135
Lawrence, Mass., death rates 102
sewage analyses 4, 5, 10, 22, 29, 31
experiment station, *see* Massachusetts State Board of Health.
Leadville, Colo., strainers 578
Leal, Dr. J. L. 113, 730
Lederer, Dr. A. 43, 49, 421, 590
Lederle, Dr. E. J. 113, 136
Lee, Dr. C. E. 556
Leeds, England, sewage analyses 12, 22
tests 197
sprinkling filters 691
Leeds, Prof. A. R. 220
Leffmann, Prof. H. 134
Leicester, England, sewage analyses 12, 22
Leicester, Mass., sand filtration 663
sewage analyses 619– 20
Leighton, M. O. 246

PAGE
Leipzig, Germany, sewage tests ... 199
sprinkling filters ... 708
Letheby, Dr ... 3– 4
Letts, Prof. E. A ... 353– 54
Levin ... 141
Lincoln, Nebr., diarrhea and typhoid epidemics ... 119– 20
Lindsay, Canada, ozonization of water ... 732
Littlehales, G. W ... 367
London, England, sewage analyses ... 3–4, 8–9, 12, 22
typhoid fever epidemic ... 136
Long Branch, N. J., strainers ... 578
Long, Prof. J. H ... 224
Los Angeles, Calif., masonry injured by sulphureted hydrogen ... 75– 76
sewage disposal methods ... 370– 72
farming ... 597
Louisville, Ky., electrolytic water tests ... 557– 74
Lowcock ... 722
Lowell, Mass., diarrhea epidemic ... 118
Lumsden, Dr. L. L ... 103

MacDonald, A. B ... 542
Machynlleth, England, slate beds ... 583
MacNeal, W. J ... 45
MacNutt, J. S ... 109, 114
McDowell, R. F ... 498
McGowan, Dr. G ... 39
McLaughlin, Dr. A. J ... 306, 308
Mackin, J ... 317
Madison-Chatham, N. J., contact filters ... 676
Imhoff tank ... 507– 09
sand filtration ... 618, 665
Madison, Wisc., lake pollution at ... 316– 17
sprinkling filters ... 691– 93
Maetzel, H ... 400
Maignen, P. A ... 603
Manahan, E. G ... 494
Manchester, England, grit chambers ... 402
sewage analyses ... 12, 22
tests ... 197
typhoid fever epidemic ... 136
Mansfield, Ohio, contact filters ... 668
septic tanks ... 489–90, 494
Marchant, R. W., Jr ... 661
Marlboro, Mass., sand filtration ... 663
sewage analyses ... 6–7, 11, 22, 29
sludge bed ... 451
Marshall, Prof. C. E ... 48, 80, 84, 95
Marshall, Gen. W. L ... 344
Marsson, Dr. M ... 77, 211, 264– 74
Marston, Prof. A ... 737
Mason, Prof. W. P ... 220, 721
Masonry injured by sewage ... 75– 77
Massachusetts data in re sewage constituents ... 4, 6, 619–20, 626
Institute of Technology ... 8, 75, 185, 194–95, 524–26, 671, 714
sewage disposal experiments ... 187– 89
State Board of Health ... 4, 6–12, 16, 21, 25–26, 28–29, 31, 33, 59, 61, 64, 66, 70, 74, 118–19, 121, 151–52, 187–89, 196, 220, 223, 230–37, 241–45, 253–58, 323–30, 333–38, 421, 433, 451, 459, 467–68, 481, 484, 539–42, 577–78, 584, 592, 617, 619–23, 628–31, 635–38, 643–44, 653, 662–63, 675, 684, 690–91, 694, 703, 710, 737
typhoid fever death rates ... 185

PAGE
Mattill, H. A. 45
Mechanical filtration 592– 93
Medfield, Mass., sand filtration 666
strainers 577– 78
Meeker ozone process 733
Merchantville, N. J., sand filtration 618
Merrimac river, sanitary condition of 253– 58
Merrit & Co. 436, 684, 686, 717
Merthyr-Tydvil, Wales, intermittent sand filtration 616
sewage farming 616
Metcalf, L. 369, 469, 527
Methane in lakes 293
sewage decomposition 83, 92–95
Metropolitan Sewerage Commission, N. Y. 14, 22, 352– 65
Middletown, Conn., typhoid fever epidemic 132– 33
Mille, M. 197, 595, 605
Miller, S. F. 716– 17
Mills, H. F. 107, 109–11, 121, 187, 617
Milwaukee, Wis., lake pollution at 305, 312– 16
sludge disposal 453
Mineralization 80
Minervini 141
Montefiore Home, Bedford Hills, N. Y., disposal plant 179, 735– 36
Montreal, P. Q., ozonization of water 732
Moore, R. 330, 536
Morrill, A. B. 94, 97
Morristown, N. J., contact filters 680
sand filtration 618, 665
Morse, Dr. F. L. 118
Morton, D. H. 542
Mosny, Dr. 134
Mount Vernon, N. Y., sprinkling filters 693, 701, 710, 715
Mueller, Dr. A. 616
Müntz 616
Murphy, Dr. 136
Mystic Valley, Mass., chemical precipitation 539

Nash, Dr. 135
Natick, Mass., sand filtration 663
National Board of Health 88
Newark, N. J., typhoid fever death rates 101
New Bedford, Mass., sewage disposal project 369– 70
typhoid fever death rates 369
New Brunswick, N. J., hypochlorite sterilization 178, 331, 730
screens 730
New Jersey State Board of Health 152– 54, 733
New Orleans, La., sewage disposal by dilution 207
methods 176– 77
Newport, R. I., test filters 579
New Rochelle, N. Y., chemical precipitation 539
Newsholme, Dr. A. 136
Newton, Gen. 339
New York bay, sewage pollution of 351– 68
City, ozonization of water 732
reservoir stripping 62
sewage analyses 22–23, 42
proposed aeration of 723– 25
harbor, sewage pollution of 339– 40
Niagara Falls, N. Y., ozonization of water 732
Nichols, Prof. W. R. 62–64, 68, 223

PAGE
Nitrification and denitrification of organic matter ... 71–72
relation of septicization to ... 468
temperature and sewage composition to ... 637– 41
Nitrogen in lakes ... 292– 93
sewage ... 3–7, 10–12, 28–29, 84, 92–95
Niven, Dr ... 136, 145– 46
North Attleboro, Mass., sand filtration ... 660– 61
sedimentation tanks ... 439
sludge bed ... 451
North Plainfield, N. J., Imhoff tank ... 508, 510
sludge drying bed ... 515
sprinkling filters ... 694, 704
Norwich, England, Hampton septic tank ... 505, 591
Nuneaton, England, sewage attacks on masonry ... 75
Nuisances due to sewage odors ... 98

Odors, facilol as a deodorant ... 452
isolation ... 98
methods of guarding against ... 88–91
minimizing of ... 88
objectionable, nature of ... 91–95
relation to aerial conditions ... 96
sewage bacteria ... 86–99
sulphureted hydrogen ... 74, 95–99
See also Broad irrigation. Chemical precipitation. Contact filters Hampton tanks. Imhoff tanks. Intermittent sand filters. Strainers. Septicization. Slate beds. Sludge beds. Sprinkling filters.
Ogden, Prof. H. N ... 316
Ohio State Board of Health ... 191, 237–40, 489, 491, 493, 499, 623–24, 654, 668
Ohm's law ... 562
Oklahoma City, Okla., electrolytic sewage plant ... 556
Olcott, Col. G. E ... 736
Opplen, Germany, influence of temperature on sedimentation ... 423
Organic matter, behavior in water ... 61
in lakes ... 295– 96
sewage ... 27–32
nitrification and denitrification of ... 71–72
removed by sedimentation ... 421
stability, *see* Stability.
Osgood, J. O ... 668
Oswego, N. Y., lake pollution at ... 312
Otto ozone process ... 733
Oversepticization ... 468
Oxygen, atmospheric, in streams ... 218– 19
balance ... 214– 16
consumed by sewage ... 6–7, 10–13, 16, 18, 30–31, 39, 67, 69, 722
dissolved in lakes ... 285– 90
New York harbor ... 352
septic effluents ... 493
sewage ... 26–77
initial, in streams ... 219– 20
relation of, to electrolysis ... 367– 69
freedom from odors ... 91, 98
intermittency ... 628– 29
nitrification ... 629
oxidation ... 721– 34
salt water disposal ... 318
residual in New York harbor ... 352
streams ... 217
saturation quantities in fresh water ... 219
salt water ... 353

PAGE

Oysters, *see* Shellfish.
Ozonisation of sewage 732– 34

Pacific Flush Tank Co 506, 655, 684, 686, 713, 717
Paris, France, sewage farming 604– 10
tests 197– 98
Pasadena, Calif., sewage farming 597– 98
Pasquier, Dr 131
Passaic, N. J., death rates 112
Passaic Valley, N. J., sewage disposal project 340– 55
Pasteur, L. 50–51, 80
Patents on septic tanks 469– 70, 526– 32
Paterson, N. J., death rates 102, 112
trade wastes 21
Pawtucket, R. I., sand filtration 643
Pearse, L. 8, 13, 94, 258, 414, 455, 503, 526, 653
Pease, Dr. H. D 169
Pennsylvania State Department of Health 117–18, 731
Petri 77
Phelps, Prof. E. B 8, 34, 39–44, 49, 75, 81, 91, 214, 217, 331, 360–64, 367, 370, 403, 421, 488, 524, 628, 665, 671, 699, 711, 714, 723– 25, 727– 28
Philadelphia, Pa., Imhoff tank 507
sewage analyses 10, 22
data, 1911 ..... 8, 10
testing station 8, 39, 584, 669, 692
sludge disposal 454
sprinkling filters 693
Philbrick, E. S. 736
Phillips, A. E. 206, 385, 404
Phosphine 84, 95
Phosphoric acid 4
Pittsfield, Mass., sand filtration 655, 663
sewage analyses 619– 20
Plankton in lakes 296–304
Plainfield, N. J., contact filters 668, 671–75, 679, 638–84, 688
sand filter odors 601, 661
screens 382– 84
septic tanks 486–87, 489–90, 496– 97
sewage analyses 9, 22, 26– 27
Pollution laws 183
Porter, Dr. E. 154
Potash 4, 602– 03
Potts, C. 656–58, 665, 680
Pratt, R. W. 9, 220, 309, 737– 38
Providence, R. I., chemical precipitation 535–37, 546– 49
hypochlorite process 730
sewage analyses 10, 22
disposal methods 330
street washings 13
trade wastes 13
Pullman, Ill., sewage farming 597
Putrefaction, definition of 52– 57
distinguished from fermentation 52– 58
in alimentary canal 58
reservoirs 65
products 52– 58
relation to bacteria 55
odors 54– 59
oxygen 55– 59

PAGE
Putrescibility, *see* Stability.
Rafter, G. W.....176, 223, 261–62, 403, 433, 535, 537, 577–78, 595–97, 602–03, 721
Rauch, Dr. J. H.....223
Ravenna, Ohio, sand filtration.....656– 58
Reading, Pa., hypochlorite treatment.....731
rotary screen.....386– 91
sedimentation.....419–20, 441, 448
sewage analyses.....9, 26
disposal methods.....179, 502
sprinkling filters.....693–95, 703, 708, 712– 16
Reaeration in New York harbor.....353, 364– 66
streams.....220
Recklinghausen, Germany, first Imhoff tank.....506
Red Bank, N. J., hypochlorite treatment.....178, 330– 31
Reece, Dr.....132
Reincke, Dr. J. J.....100, 107, 109
Residential and institutional disposal methods.....735– 38
Residual oxygen in salt water.....353
streams.....217
Richards, E. H.....617
Richards, J. W.....72
Richardson, Sir D. W.....131
Rideal, Dr. S.....483, 727
Ridgewood, N. J., contact filters.....686– 87
Riverton, N. J., hypochlorite treatment.....178, 730
Robertson, Dr. J.....702
Rochester, N. Y., lake disposal at.....311
screens.....386
Roebling, N. J., sand filtration.....618
screens.....384
Roechling, H. A.....610– 12
Roland Park, Md., sand filtration.....661– 62
Rome, N. Y., Imhoff tank.....507
sprinkling filters.....694
Roscoe, Sir H.....29, 31, 550
Rosenau, Dr. M. J.....103
Roughing filters.....376, 578–79, 581– 83
Royal Commission on River Pollution of Great Britain.....5
Sewage Disposal of Great Britain....9, 29, 31, 39, 77, 142, 147, 181, 197, 209, 583, 595
Rugby, England, sewage analyses.....3
Ruggles, W. B.....462
Russell, H. L.....122, 141–42, 250
Rust, C. H.....307

Salathé, Prof.....555
Salford, England, sprinkling filters.....691, 708
Salt Lake City, Utah, sewage farming.....598
Sanborn, M. F.....339
Santa Monica, Calif., electrolytic sewage plant.....553– 56
Saratoga Springs, N. Y., dosing apparatus.....661
septic tank, covered.....424
litigation.....469–70, 526– 28
Saville, C.....94, 402, 425, 437, 448, 455, 500, 506, 517, 591
Schaefer-ter Meer sludge drying machine.....460– 61
Schloesing.....616
Schmeitzner, Dr. R.....402–03, 423, 427, 430, 448, 452
Schmidt.....423
Schneller ozone process.....733
Scott, R. D.....498

PAGE
Screens 375, 378–92
analyses of sludge from 391
different kinds 379–81
efficiency 381
mechanical appliances 384–86
medium-sized 381–82
rotary 386–91
utility of 378–79
Scum formation in septic tanks 486–87
Seasonal effects on polluted streams 220–21
Sedgwick, Prof. W. T 109, 114, 184–85, 188, 194, 323, 370, 727
Sedimentation 375–76, 393–465
analyses 400, 415–20, 446–47
bacteria, removal of 421
economical limits 422
effect of flocculation and coagulation 411–12
temperature 411–23
efficiency 413–23
features of design 424–32
grease removal 405–06
grit chambers 396–404
history and extent of use 394–96
influence of age and strength of sewage 422–23
period of detention 402, 425
skimming tank 404–05
sludge, quantity of 442–47
removal details 438–42
treatment and disposal 449–63
tanks and basins, frequency of cleaning 447–48
types of 424–32
theory of 406–13
utility of 421–22
velocity of flow 401, 425
settling particles 409–11
Self-purification of streams 207–11
Septicization with sedimentation (septic tanks) 376, 466–534
analyses 471, 481–93, 507
bacterial removal 472–73
cleaning operations 4494–95
clogging aspects 66–67
covers for tanks 500
different types of tanks 474–79, 500–32
Dortmund tanks 475
effect upon organic matter 467
efficiency and utility 470–74
enzymes, action of 482
gases from 479–80, 483–87
gasification 479–80, 483–84
history and uses 468–70
Imhoff tanks 199, 331, 505–24
odors 484–86, 495–500, 523
oversepticization 468
patent litigation 469–70, 526–32
relation to nitrification 468
removal of bacteria 472–75
scum, formation of 486–87
size of tanks 492
sludge digestion 468
solids, digestion of 487–89
Travis or Hampton tanks 474–75, 503–05
two phases of process 466

PAGE

Settling tanks, *see* Sedimentation.
Sewage, aeration of....91, 721– 25
bacteria, importance of.... 2
composition.... 1–49
ammonia....84, 92– 95
bacteria.... 44
chlorine.... 5–7, 10–13, 16, 18, 727– 28
computed analyses.... 15
dangers of limited data.... 17
early records.... 3
English data.... 5
fats....6–7, 10, 13, 18, 25– 26
influence of local conditions.... 14
Massachusetts data.... 4, 6
nitrogen....3–7, 10–12, 28–29, 84, 92– 95
organic matter.... 39, 421
oxygen consumed....6–13, 16–18, 30– 31
dissolved.... 26–27, 285– 90, 352, 493
See also Oxygen.
potash.... 4, 602– 03
recent records.... 8
solid matters.... 4–14, 21, 413– 19
trade wastes....13–14, 20–21, 198, 202, 653– 54
variations in quantity and quality.... 16
decomposition.... 50– 85
aerobic and anaerobic.... 50, 87
fermentation and putrefaction.... 52– 58
odors, minimizing of.... 88
phosphine.... 84, 95
processes, classification of.... 58– 59
products.... 81– 84
rate of in fresh and salt water.... 333– 38
relation to nuisances.... 86– 87
residual results.... 80– 82
definition of.... 50
disposal, American experiments.... 187– 91
benefits of plants.... 185– 86
different types of.... 176– 79
economical aspects of problems.... 179– 80
European experiments.... 196–200
experimental methods.... 184–200
general.... 2
Massachusetts experiments.... 187– 89
new conditions encountered.... 186– 87
objects of experiments.... 191– 96
pollut'on laws.... 183
practical accomplishments at lake cities.... 304– 17
relation to public water supplies....180–82, 240
shellfish.... 182
wide range in conditions....175– 79
See also Broad irrigation. Chemical precipitation. Contact filters. Dilution. Electrolytic treatment. Institutional and residential plant methods. Intermittent sand filtration. Sewage treatment works.
farming (broad irrigation).... 595–614
fresh.... 68–71
general characteristics.... 1
mud.... 202, 319
oxidation.... 87–88
putrescibility of, *see* Stability.
reduction.... 87–88

PAGE

(Sewage,) septic ... 68–71
skimming tank ... 404–05
solids in streams ... 210
stale ... 68–71
treatment works ... 373–77
absence of standard methods ... 739
broad irrigation ... 595–614
chemical precipitation ... 376, 535–49
combinations and modifications ... 377
comparative efficiency and cost ... 741–43
summary ... 739–44
contact filters ... 667–80
electrolytic treatment ... 550–76
filtration ... 376
general classification ... 739–41
intermittent sand filters ... 615–66
need for good management ... 744
objects sought ... 373–74
ozonization ... 732–34
roughing filters ... 376, 578–79, 581–83
screening ... 375, 378–92
sedimentation ... 375–76, 393–465
septicization ... 376, 466–534
slate beds ... 376, 583–94
sprinkling filters ... 690–720
sterilization ... 376–77, 726–31
strainers ... 376, 577–83
Sewer flushing ... 90
Sewers, aeration of ... 91
house connections ... 89
interior surfaces ... 90
seeding ... 90
velocities, non-subsiding ... 89
ventilation ... 89
Sharp, Dr. ... 134
Sheffield, England, sewage analyses ... 12, 22
Shelby, Ohio, sand filtration ... 654
Shellfish, American Public Health Association report ... 169–70
bacteria in from unpolluted sea water ... 141
waters ... 143–44
B. typhosus in oysters ... 144
Federal authorities on pollution ... 154–60
hibernation ... 150
inspection of layings ... 148–49
legal decisions regarding pollution ... 170–74
life history of oyster ... 137–39
pollution on outside of oysters ... 147
products ... 125–31
records of disease transmission ... 131–35
See also Various cities.
relation to sewage bacteria ... 125–74
disposal ... 182
typhoid fever ... 135–36
relaying of oysters ... 147
State authorities on pollution ... 151–54, 167–69
"The Oysterman's Viewpoint" ... 160–67
typhoid germs in oysters and water ... 139–40
sea water ... 140
Shields, W. S. ... 502
Siemens ozone process ... 733
Skatol ... 55, 92

PAGE
Slate beds 376, 583–90
odors 584
Sludge analyses 446–47
banks in streams 201
beds, odors from 451
digestion in septic tanks 468
odors from 456
disposal and treatment in plain sedimentation 449–63
in chemical precipitation 546–47
water 453–54
drying beds 451–53, 514–17
mechanical 460
from septic tanks 489–92
of Chicago drainage canal 259
pressing 449–51, 546–47
removal from sedimentation tanks 438–42
volume of 23–24, 442–47
weight of 23, 445–47
Smith, Dr. T 333
Snow, F. H 117, 311, 390, 645, 668
Solid matters in sewage 21–25, 413–19, 487–89
Soper, Dr. G. A 135, 147, 351
Southampton, England, typhoid fever epidemic 133
Southbridge, Mass., sand filtration 663
Southend-on-Sea, England, typhoid fever epidemic 135
Spencer, Mass., sand filtration 663
sewage analyses 7, 619–20
Spillner, Dr. F 94, 517, 523
Spitta, Dr. O 38
Sprinkling filters 697–720
analyses 695–96
capacity 697–98
characteristics of process 700–01
construction features 704–18
costs of construction and operation 719
distributing devices 710–15
efficiency 694–97
extent of use 693–94
influence of strength of sewage 698
material, character of 702–04
size and depth of 702–04
nomenclature and historical development 690–93
nozzles, types of 710–16
odor question 718–19
present status 693
relation to preliminary and final treatment 698–99
Stabler, Prof. L. J 555
Stability, relative 36
tests 32–44
St. Andre de Sangonis, France, typhoid fever epidemic 134
Stearns, F. P 4, 188, 205, 213, 231–37, 332, 475, 625, 718
Sterilization of sewage 178, 213, 330–32, 370, 376–77, 708, 726–31
See also Various cities.
Steynis ozone process 733
Stiles, Dr. C. W 147
Stockbridge, Mass., sand filtration 663
sewage analyses 619–20
Stoddard 691
Stokes, Dr. W. R 169
Strainers 376, 577–83
odors 579

PAGE
Streams, analyses 232–34, 242–43, 247–48, 256– 61
dilution in 201– 76
self-purification of 207–11, 220, 261– 74
Sulphate of alumina in chemical precipitation 543
Sulphur bacteria, Beggiatoa 78
Spirillum desulfuricans 76, 78
Thiothrix 78
consumption of, by bacteria 78– 80
desulphurization 72– 77
formation of sulphuric acid 73– 76
odors, control of 95– 98
reduction of mineral sulphates 72– 76
organic matter 77– 80
relation to bacteria 77– 80
sulphureted hydrogen, formation of 73– 80
sulphuric acid, formation by sewage 73– 76
Suspended solids 23

Taunton, England, cholera epidemic 131
Taylor, G. M 542
Taylor, W. G 8, 350
Temperature, influence on sedimentation 411, 423
Thermal stratification in lakes 279– 81
Thorne, Sir R 132
Thumm, Dr. K 677
Thwaites, W 485, 613
Tilburg, Holland, sewage tests 198
Time factor in dilution methods 222
Tindal ozone process 733
Togus, Me., contact filters 683, 686
sand filtration 665
sewage disposal plant 736
Toronto, Canada, lake pollution at 306– 08
sedimentation tanks 439– 40
sludge disposal 456
Trade wastes 13–14, 20–21, 198, 202
relation to sand filters 653– 54
Travis, Dr. W. O 474–75, 502–03, 505, 512, 585– 91
septic tanks 474– 75
Trenton, N. J., ozone sewage plant 732– 34
Truro, England, typhoid fever epidemic 133– 34
Typhoid fever germs in oysters and water 139– 46
sea water 140
longevity of in water 119– 23
imported cases 105
relation to bacillus carriers 105– 06
"contact" 105
flies 105
milk 105– 06
polluted water 100– 17
servants 105
sewerage system 105
shellfish 105, 135– 36
water supply 107– 11

United States Board of Food and Drug Inspection 154– 58

Van Ornum 598
Vegetables, relation to broad irrigation 599
Velocities, non-subsiding 89–90
of flow in dilution methods 202, 319
sedimentation tanks 401, 425

PAGE
Ventilation of sewers ... 89
Verviers, Belgium, sewage tests ... 198
Vincennes, Ind., screens ... 380
Virchow, R. ... 595
Viscosity, influence on sedimentation ... 426
Voelcker, Dr. J. A. ... 3, 603
Voids in contact filters ... 678–79
Vrooman, M. ... 8, 20–21, 68, 436, 451

Wandsbeck, Germany, cholera epidemic ... 101
Waring, Col. G. E., Jr. ... 579, 691, 722, 736
Warington, Dr. ... 617
Warren, Pa., gastro-enteritis epidemic ... 117–18
Washington, D. C., death rates ... 102–04
sewage disposal by dilution ... 205–07
skimming tank ... 404–05
typhoid experiences ... 102–06
Washington, N. J., sand filtration ... 618
Washington, Pa., screens ... 380
sprinkling filters ... 693
Waterbury, Conn., sewage analyses ... 10, 22
testing station ... 8, 669, 692
sprinkling filters ... 693
Water supply, relation of to bacteria ... 100–24
death rates ... 107–20
sewage disposal ... 180–82
typhoid fever ... 107–20
Watertown, N. Y., death rates ... 102
Watson, J. D ... 9, 307, 434, 439, 456, 580, 613, 699
Wayne, Pa., sprinkling filters ... 692
Way ... 3
Weand, O. M ... 380, 386–91, 693, 704
Webster, A. L. ... 736
Webster, G. S. ... 8, 425, 697
Webster electrolytic process ... 550–53, 729
Weldert, Dr. R. ... 38
Westboro, Mass., sand filtration ... 654,
sewage analyses ... 11, 619–20
Weston, R. S. ... 207
Whipple, G. C. ... 21, 121, 142, 169, 213, 263, 308, 314
White Plains, N. Y., chemical precipitation ... 539
Whitman, E. B. ... 316
Williams & Whitman ... 316
Williams, B. ... 224
Williams, Proctor & Potts ... 658
Williams, Prof. C. C. ... 598, 601
Williams, R. B. ... 316
Williams, W. F. ... 369
Williamson, Dr. ... 146
Willow Grove, Pa., sprinkling filters ... 692
Winchester, England, typhoid fever ... 133
Winchester, Ky., Imhoff tank ... 507
Winogradsky, S. ... 72, 79, 617
Winslow, Prof. C.-E. A. ... 8–9, 75, 220, 403, 421, 488, 524–26, 628, 671, 699, 711, 714
Winters, Calif., Imhoff tank ... 507
Wisner, G. M ... 14, 214, 216, 218, 220, 258–61, 364, 380, 437, 507, 698, 722
Witt ... 3
Wood, Gen. L. ... 343
Woodhead, Dr. S. ... 50
Woodward, Dr. W. C. ... 106
Woolf electrolytic process ... 729

PAGE
Worcester, Mass., chemical precipitation 537–38, 543–45, 547– 48
grit chambers 400– 01
Imhoff tank 507
sand filtration 650– 53
sedimentation tanks 448
sewage analyses 4–5, 10, 22, 29
attacks on masonry 75
sludge incineration 459
trade wastes 5, 21
Worms and flies in contact filters 684
sprinkling filters 701

Yarmouth, England, typhoid fever 135– 36
York, Pa., death rates 102

Zeit, F. R. 122, 250

89088902226

B89088902226A